DOCUMENT RESUME

ED 450 548		EF 005 845
TITLE	Design and Construction Guidance for Community Shelters. FEMA 361.	
INSTITUTION	Federal Emergency Management Agency, Washington, DC.	
PUB DATE	2000-07-00	
NOTE	276p.; A CD-ROM on Benefit-Cost Analysis Software for Hurricane and Tornado Shelters is not available from ERIC.	
PUB TYPE	Guides - Non-Classroom (055)	
EDRS PRICE	MF01/PC12 Plus Postage.	
DESCRIPTORS	Case Studies; Construction Costs; *Facility Guidelines; Facility Planning; *Facility Requirements; *Public Facilities	
IDENTIFIERS	*Emergency Shelters	

ABSTRACT

This manual presents guidance to engineers, architects, building officials, and prospective shelter owners concerning the design and construction of community shelters that will provide protection during tornado and hurricane events. The manual covers two types of community shelters: stand-alone shelters designed to withstand high winds and the impact of windborne debris during tornadoes, hurricanes, or other extreme-wind events; and internal shelters specially designed within an existing building to provide the same wind and missile protection. The shelters are intended to provide protection during a short-term, high-wind event, such as a tornado or hurricane. Shelter location, design loads, performance criteria, and human factor criteria that should be considered for the design and construction of such shelters are provided, as are case studies to illustrate how to evaluate existing shelter areas, make shelter selections, and provide construction drawings, emergency operation plans, and cost estimates. Included in the appendices is a case study involving a school shelter design in Kansas. Other appendices provide site assessment checklists; a benefit-cost analysis model for tornado and hurricane shelters; another case study of a stand-alone community shelter (North Carolina); wall sections, doors, and hardware that passed the missile impact tests; and design guidance on missile impact protection levels for wood sheathing. (GR)

FIRST EDITION July 2000

Design and Construction Guidance for Community Shelters

American Red Cross

INTERNATIONAL CODE COUNCIL®

PROJECT IMPACT

CLEMSON UNIVERSITY

WIND ENGINEERING RESEARCH CENTER

TEXAS TECH UNIVERSITY

Federal Emergency Management Agency
Mitigation Directorate
www.fema.gov

Preface

Having personally seen the devastation caused by natural disasters, I am heartened to now see hundreds of communities commit to becoming disaster-resistant through FEMA's nationwide initiative, Project Impact. Project Impact operates on three simple principles: preventive actions must be decided at the local level; private sector participation is vital; and long-term efforts and investments in prevention measures are essential. The Federal Emergency Management Agency is committed to continue to develop tools, such as this manual, to help individuals, communities, states, and others create sustainable, disaster-resistant communities.

When severe weather threatens, individuals and families need to have a safe place to go and time to get there. Thousands of safe rooms have been built based on FEMA designs, providing protection for families in their homes. Where will these people go if they are not at home? This manual provides specific guidance on how to provide effective shelter that can save lives when severe weather threatens away from home.

James L. Witt

James L. Witt
Director, Federal Emergency Management Agency

Table of Contents

Appendixes

Figures

Tables

Formulas

Project Team

The Project Team comprised engineers from FEMA's Mitigation Directorate, consulting design engineering firms, and university research institutions. The role of the Project Team was to follow the plan indicated by the Conceptual Report and produce this guidance manual. All engineering and testing efforts required to complete this project were performed by the Project Team.

FEMA

Clifford Oliver, CEM, CBCP
Chief – Building Sciences and Assessment Branch, Mitigation Directorate

Paul Tertell, P.E.
Project Officer and Senior Engineer – Building Sciences and Assessment Branch, Mitigation Directorate

CONSULTANTS

William Coulbourne, P.E.
Sr. Structural Engineer and Department Head – Natural Hazards Engineering, Greenhorne & O'Mara, Inc.

Ernst Kiesling, Ph.D., P.E.
Director of Shelter Program, Wind Engineering Research Center – Texas Tech University

Daniel Medina, Ph.D., P.E.
Engineer – Dewberry & Davis, LLC

Kishor Mehta, Ph.D., P.E.
Director, Wind Engineering Research Center – Texas Tech University

Shane Parson, Ph.D.
Water Resources Engineer – Dewberry & Davis, LLC

Robert Pendley
Technical Writer – Greenhorne & O'Mara, Inc.

Scott Schiff, Ph.D.
Associate Professor of Civil Engineering – Clemson University

Scott Tezak, P.E.
Task Manager, Structural Engineer – Greenhorne & O'Mara, Inc.

Acknowledgments

The American Red Cross, Clemson University, ICC, Texas Tech University, and the U.S. Department of Education assisted FEMA in the preparation of this manual by providing invaluable guidance and participating on the project Review Committee. FEMA reserved the right to make final decisions concerning the content of this manual based on the guidance and information provided by these organizations, associations, and research institutions.

The following individuals made significant contributions to this manual, the testing of materials for this manual, and the development of design and performance criteria presented in the manual.

Eugene Brislin, Jr., P.E.
Structural Engineer

Wes Britson, P.E.
Professional Engineering Consultants, Wichita, KS

Russell Carter, E.I.T.
Wind Engineering Research Center – Texas Tech University

Gene Corley, Ph.D., S.E., P.E.
Vice President – Construction Technology Laboratories, Inc.

David Low, P.E.
Structural Engineer – Greenhorne & O'Mara, Inc.

Norland Plastics, Haysville, KS

Timothy Reinhold, Ph.D.
Associate Professor of Civil Engineering – Clemson University

Joseph Schaefer, Ph.D.
Storm Prediction Center, National Oceanic and Atmospheric Administration

Emil Simiu, Ph.D.
Structures Division, National Institute of Standards and Technology

Larry Tanner, R.A., P.E.
Wind Engineering Research Center – Texas Tech University

Review Committee

The Review Committee was composed of design professionals; representatives of Federal, state, and local governments; and members of public and private sector groups that represent the potential owners and operators of community shelters. The role of the Review Committee was to provide peer, industry, and user group review for the guidance manual. The committee helped direct the development of shelter design and construction guidance to ensure that the information presented in this manual is accurate, clear, and useful to the intended users.

Review Committee Members – Attending Members

Kent Baxter – FEMA, Region VI, Denton, TX

Larry K. Blackledge – Blackledge and Associates: Architects

John Cochran – FEMA, United States Fire Administration

Doug Cole – Manufactured Home Park Owner

Glenn Fiedelholtz – FEMA, Preparedness, Training, and Exercise Directorate, Washington, DC

Robert Franke – FEMA, Region VII, Kansas City, MO

John Gambel – FEMA, Mitigation Directorate, Washington, DC

Louis Garcia – American Red Cross

Michael Gaus – Professor, University of Buffalo

Danny Ghorbani – Manufactured Housing Association for Regulatory Reform

Dirk Haire – Associated General Contractors of America

Dave Hattis – Building Technology Incorporated

E. Jackson, Jr. – American Institute of Architects

Aziz Khondker – ESG, Inc.

Danny Kilcollins – National Emergency Management Association

Fred Krimgold – Virginia Tech, Northern Virginia Center

Edward Laatsch – FEMA, Mitigation Directorate, Washington, DC

Randolph Langenbach – FEMA, Infrastructure Division

Emmanuel Levy – Manufactured Housing Research Alliance

John Lyons – U.S. Department of Education, Office of the Director

Robert McCluer – Building Officials and Code Administrators International, Inc.

Rick Mendlen – U.S. Department of Housing and Urban Development, Office of Consumer Affairs

Charles Moore – Kansas Department on Aging

Peggy Mott – American Red Cross, Planning and Evaluation Directorate

Mark Nunn – Manufactured Housing Institute

Steven Pardue – FEMA, Mitigation Directorate, Washington, DC

Jim Rossberg – American Society of Civil Engineers

Joseph T. Schaefer. Ph.D. – Storm Prediction Center, National Oceanic and Atmospheric Administration

Corey Schultz – PBA Architects

Emil Simiu, Ph.D. – U.S. Department of Commerce, National Institute of Standards and Technology, Structures Division

Robert Solomon – National Fire Protection Association, Chief of Building Engineering

Eric Stafford – Southern Building Code Congress International, Inc.

Dan Summers – International Association of Emergency Managers

S. Shyam Sunder – U.S. Department of Commerce, National Institute of Standards and Technology, Structures Division

Carol W. Thiel – Maryland Emergency Management Agency

William Wall – International Conference of Building Officials

Jarrell Williams – Manufactured Home Park Owner

Soy Williams – International Code Council, Inc.

Review Committee Members – Corresponding Members

Deborah Chapman – National Foundation of Manufactured Housing Owners, Inc.

Jim Fearing – Fearing & Hagenauer Architects, Inc.

Daniel Gallucci – New Necessities, Inc.

Robert Hull – Assistant Superintendent of Operations, Olathe School District, Kansas

Larry Karch – State Farm Insurance Companies, Facilities Management Division

Mark Levitan – Civil and Environmental Engineering, Louisiana State University

Jerry McHale – Federation of Manufactured Housing Owners of Florida, Inc.

Dick Nystrom – State Farm Insurance Companies, Facilities Management Division

Janet Potter – National Foundation of Manufactured Housing Owners

Audrey Staight – American Association of Retired Persons, Public Policy Institute

Lynn White – National Child Care Association

Acronyms and Abbreviations

The following acronyms and abbreviations are used in this manual.

Acronyms

ACI – American Concrete Institute International

ADA – Americans with Disabilities Act

APC – atmospheric pressure change

ASCE – American Society of Civil Engineers

ASD – Allowable Stress Design

B/C – benefit/cost

BPAT – Building Performance Assessment Team

C&C – components and cladding

CMU – concrete masonry unit

EOC – Emergency Operations Center

FEMA – Federal Emergency Management Agency

HAZMAT – hazardous material

HVAC – heating, ventilating, and conditioning

IBC – International Building Code

ICC – International Code Council

ICF – insulating concrete forms

IDR – Institute for Disaster Research

IMC – International Mechanical Code

IRC – International Residential Code

LRFD – Load and Resistance Factor Design

MRI – mean recurrence interval

MWFRS – main wind force resisting system

NCDC – National Climatic Data Center

NEHRP – National Earthquake Hazard Reduction Program

NFIP – National Flood Insurance Program

NOAA – National Oceanic and Atmospheric Administration

NPC – National Performance Criteria for Tornado Shelters

NWS – National Weather Service

o.c. – on center

RCC – Regional Climate Center

RO – Regional Office

SERCC – Southeast Regional Climate Center

SFHA – Special Flood Hazard Area

SPC – Storm Prediction Center (NOAA)

TTU – Texas Tech University

UBC – Uniform Building Code

WERC – Wind Engineering Research Center (TTU)

WLTF – Wind Load Test Facility (Clemson University)

Abbreviations

C_p – external pressure coefficient (for MWFRS)

D – dead load

F – lateral force

fps – feet per second

ft^2 – square foot/square feet

G – gust effect factor

GC_p – external pressure coefficient (for C&C and attachments)

GC_{pi} – internal pressure coefficient

I – importance factor

I_e – impact energy

I_m – impact momentum

k – stiffness

K_d – directionality factor

K_z – velocity pressure exposure coefficient

K_{zt} – topographic factor

L – live load

lb – pound/pounds

M – mass

mph – miles per hour

p – pressure (in psf)

psf – pounds per square foot

psi – pounds per square inch

q_z – velocity pressure (in psf)

V – design wind speed

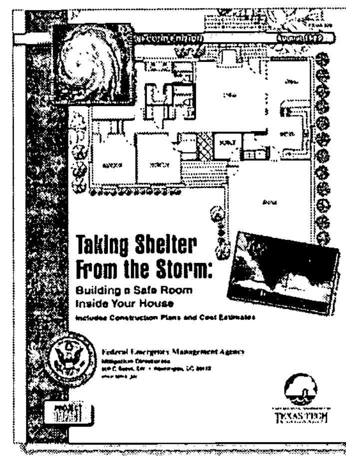
W – wind load as prescribed by code or ASCE 7-98

W_x – extreme wind load

1 Introduction

1.1 Purpose

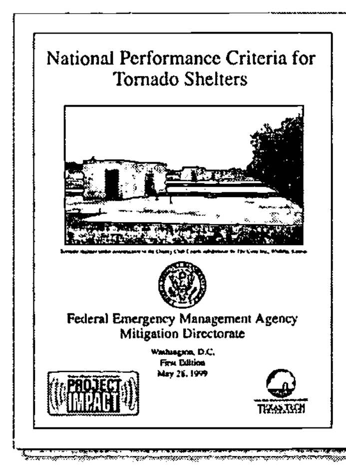
This document is a guidance manual for engineers, architects, building officials, and prospective shelter owners. It presents important information about the design and construction of community shelters that will provide protection during tornado and hurricane events. For the purpose of this manual, a *community shelter* is defined as a shelter that is designed and constructed to protect a large number of people from a natural hazard event. The number of persons taking refuge in the shelter will typically be more than 12 and could be up to several hundred or more. These numbers exceed the maximum occupancy of small, in-residence shelters recommended in FEMA 320, *Taking Shelter From the Storm: Building a Safe Room Inside Your House*.



This manual covers two types of community shelters:

- stand-alone shelter – a separate building (i.e., not within or attached to any other building) that is designed and constructed to withstand high winds and the impact of windborne debris (missiles) during tornadoes, hurricanes, or other extreme-wind events
- internal shelter – a specially designed and constructed room or area within or attached to a larger building; the shelter (room or area) is designed and constructed to be structurally independent of the larger building and to provide the same wind and missile protection as a stand-alone shelter

These shelters are intended to provide protection during a short-term high-wind event (i.e., an event that lasts no more than 36 hours) such as a tornado or hurricane. They are **not** recovery shelters intended to provide services and housing for people whose homes have been damaged or destroyed by fires, disasters, or catastrophes.



Both stand-alone and internal community shelters may be constructed near or within school buildings, hospitals and other critical facilities, nursing homes, commercial buildings, disaster recovery shelters, and other buildings or facilities occupied by large numbers of people. Stand-alone community shelters may be constructed in neighborhoods where existing homes lack shelters. Community shelters may be intended for use by the occupants of buildings they are constructed within or near, or they may be intended for use by the residents of surrounding or nearby neighborhoods or designated areas.

This manual provides detailed guidance concerning the design and construction of both stand-alone and internal community shelters for extreme-wind events—guidance that is currently not available in other design guides or in building codes or standards. This manual is a compilation of the best information available at the time of publication.

Shelters designed and constructed in accordance with the guidance presented in this manual provide "near-absolute protection" from extreme-wind events. Near-absolute protection means that, based on our knowledge of tornadoes and hurricanes, the occupants of a shelter built according to this guidance will be protected from injury or death. Our knowledge of hurricanes and tornadoes is based on substantial meteorological records as well as extensive investigations of damage from extreme winds. However, more extreme wind events may hypothetically exist, although they have not been observed. For this reason, the protection provided by these shelters is called near-absolute rather than absolute.

This manual discusses shelter location, design loads, performance criteria, and human factor criteria that should be considered for the design and construction of such shelters. Case studies—one for a stand-alone shelter and one for an internal shelter—are presented that illustrate how to evaluate existing shelter areas, make shelter selections, and provide construction drawings, emergency operation plans, and cost estimates.

Many factors may influence the decision to construct a community shelter. They include the following:

- the likelihood of an area being threatened by an extreme-wind event
- the consequences (deaths and injuries) of an extreme-wind event
- the cost of constructing a shelter

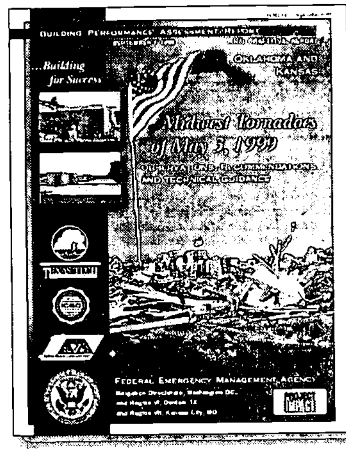
Therefore, this manual also provides decision-making tools that include shelter hazard evaluation checklists and economic analysis software. These tools provide an effective means of addressing all or many considerations that can affect the decision to either build or not build a community shelter.

1.2 Background

Sections 1.2.1 and 1.2.2 provide background information about tornadoes and hurricanes and about post-disaster assessments, research activities, and wind shelter design development carried out by the Federal Emergency Management Agency (FEMA) and other organizations.

1.2.1 Tornadoes and Hurricanes

Tornadoes and hurricanes are among the most destructive forces of nature. On average, more than 1,200 tornadoes have been reported nationwide each year since 1995. Since 1950, tornadoes have caused an average of 89 deaths and 1,521 injuries annually, as well as devastating personal and property losses. A tornado is defined as a violently rotating column of air extending from a thunderstorm to the ground. The most violent tornadoes are capable of tremendous destruction with wind speeds of 250 mph near ground level. Damage paths over 50 miles long and over 1 mile wide have been reported. Sixty-seven tornadoes struck Oklahoma and Kansas on May 3, 1999, including numerous F4 and F5 tornadoes. (F4 and F5 are classifications based on the Fujita Tornado Scale—see Table 3.1 in Chapter 3.) This tornado outbreak resulted in 49 deaths and leveled entire neighborhoods. (Additional information about the Oklahoma and Kansas tornadoes is available in the FEMA Building Performance Assessment Team report *Midwest Tornadoes of May 3, 1999*, FEMA 342.)



A hurricane is a type of tropical cyclone (the general term for all weather systems that circulate counterclockwise in the Northern Hemisphere over tropical waters) originating in the Atlantic Ocean, Caribbean Sea, or Gulf of Mexico. Around its core, winds can grow with great velocity, generating violent seas. As the storm moves ashore, it can push ocean waters inland while spawning tornadoes and producing torrential rains and floods. On average, 10 tropical storms (6 of which become hurricanes) develop each year in the Atlantic Ocean. Approximately five hurricanes strike the United States mainland every 3 years; two of those storms will be major hurricanes (Category 3 or greater on the **Saffir-Simpson Hurricane Scale**—see Table 3.2 in Chapter 3). The loss of life and property from hurricane-generated winds and floodwaters can be staggering. Tornadoes of weak to moderate intensity occasionally accompany tropical storms and hurricanes that move over land. These tornadoes are usually to the right and ahead of the path of the storm center as it comes onshore.

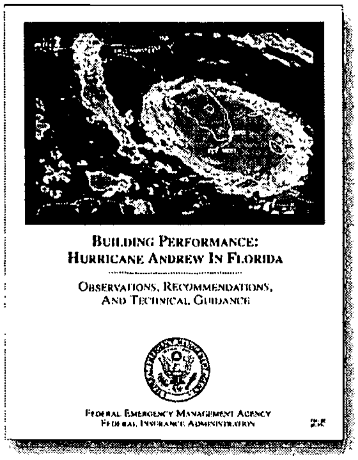
CROSS-REFERENCE

The **Saffir-Simpson Hurricane Scale** is discussed in Chapter 3.

In the western Pacific, hurricanes are called "typhoons" and affect the Pacific Islands, including Hawaii, Guam, and American Samoa; in the Indian Ocean, similar storms are called "cyclones." Like hurricanes and tornadoes, typhoons and cyclones can generate high winds, flooding, high-velocity flows, damaging waves, significant erosion, and heavy rainfall. Historically, typhoons have been classified by strength as either typhoons (storms with less than 150 mph winds) or super typhoons (storms with wind speeds of 150 mph or greater), rather than by the Saffir-Simpson Hurricane Scale.

An example of a hurricane that caused severe wind damage is Hurricane Andrew, which made landfall in southeastern Florida on August 24, 1992, generating strong winds and heavy rain over a vast portion of southern Dade

County. This Category 4 storm (which is defined as having a range of sustained wind speeds from 131 mph to 155 mph) produced high winds and high storm surge, but the most extensive damage was caused by wind. The storm caused unprecedented economic devastation; damage in the United States was in the tens of billions, making Andrew the most expensive natural disaster in U.S. history. In Dade County, the storm forces caused 15 deaths and left almost one-quarter million people temporarily homeless. (Additional information about Hurricane Andrew is provided in *Building Performance: Hurricane Andrew in Florida*, FIA-22.)



1.2.2 Post-Disaster Assessments, Research, and Design Development

When a catastrophic event such as a hurricane, tornado, or earthquake causes a natural disaster in the United States or one of its territories, FEMA frequently deploys a field investigation team consisting of representatives from FEMA Headquarters and the FEMA Regional Offices, state and local governments, and public and private sector organizations related to construction and building code development and enforcement. These teams are referred to as **Building Performance Assessment Teams** (BPATs). The objectives of a BPAT are to inspect damage to buildings, assess the performance of the buildings, evaluate design and construction practices, and evaluate building code requirements and enforcement in order to make recommendations for improving building performance in future storm events.

The BPAT Process: In response to catastrophic hurricanes, floods, tornadoes, earthquakes, and other disasters, FEMA often deploys BPATs to conduct field investigations at disaster sites. More information about the BPAT program can be found on the World Wide Web at www.fema.gov/mit/bpat.

During assessments conducted after extreme-wind events, BPATs have often found portions of otherwise destroyed buildings still standing. Frequently, these surviving portions are small rooms (e.g., a closet or bathroom) or a hallway located in the center of the building (see Figure 1-1). These observations suggest that an interior room within a house or other building could be designed and constructed to serve as a wind shelter.

Studies have been conducted since the early 1970s to determine design parameters for shelters intended to provide protection from torñadoes, hurricanes, and other extreme-wind events. In 1998, using the results of research conducted by Texas Tech University's Wind Engineering Research Center (WERC), FEMA developed design guidance and construction plans for in-home wind shelters and prepared the booklet *Taking Shelter From the Storm: Building a Safe Room Inside Your House,* FEMA 320. As the title suggests, the guidance presented in FEMA 320 is specific to small shelters built inside individual houses.

This manual builds on the information in FEMA 320 to provide design guidance for larger, community shelters for high-wind events.

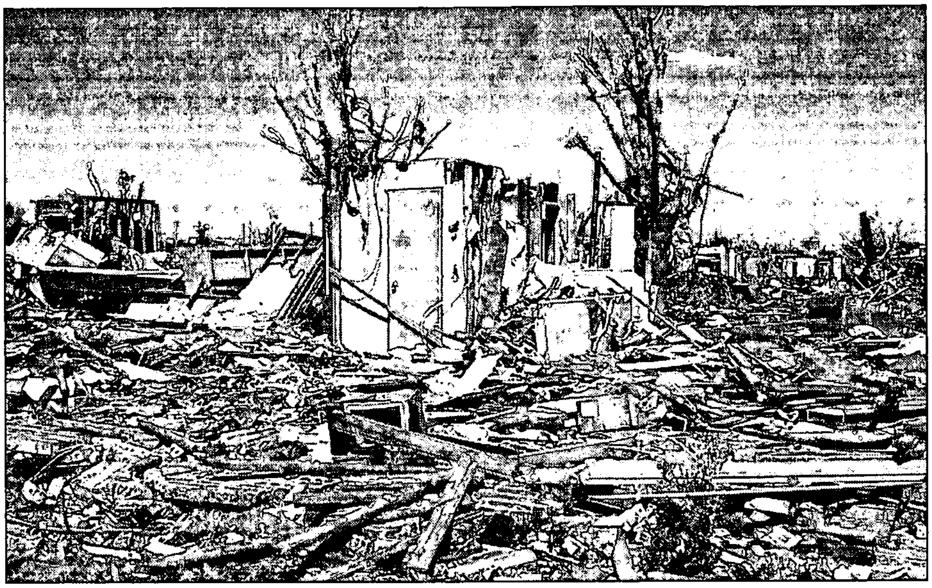


Figure 1-1
Small interior room that survived a tornado.

1.3 Organization of the Manual

This manual consists of 11 chapters and 7 appendixes:

Chapter 2 describes the objectives of designing community shelters—the primary objective is the safety of the occupants within the shelters—and discusses risk assessment tools.

Chapter 3 describes the characteristics of tornadoes and hurricanes and their effects on structures.

Chapter 4 discusses shelter location concepts, including shelters accessed from the interior or exterior of a building, modifying and upgrading existing interior space, shelter location and accessibility, and types of shelters.

Chapter 5 details the wind load design criteria for shelter structures (e.g., determination of wind loads, protection against penetration by windborne missiles, and proper anchorage and connection).

Chapter 6 presents the performance criteria for windborne missile impacts, doors and door frames, windows, and roofs.

Chapter 7 discusses considerations regarding flood and seismic hazards, permitting, code compliance, and quality control.

Chapter 8 discusses the human factors criteria for shelters (e.g., proper ventilation, square footage per shelter occupant, accessibility, lighting, occupancy durations, emergency food and water, sanitary management, emergency supplies, and emergency power).

Chapter 9 discusses emergency management considerations, including parameters for developing a plan of action to respond to a high-wind event for both community shelters and shelters in commercial buildings, and preparation of a shelter maintenance plan.

Chapter 10 presents a commentary on the design and performance criteria.

Chapter 11 presents a list of references used in the preparation of this report.

Appendix A describes the FEMA shelter benefit/cost model, which is provided on a CD-ROM included in this appendix.

Appendix B contains checklists for use in assessing wind, flood, and seismic hazards at a potential shelter site.

Appendixes C and D present case studies in which community shelters were designed for two applications. Appendix C contains design plans for a community shelter intended to protect residents of manufactured housing provided by FEMA after Hurricane Floyd in North Carolina. Appendix D contains design plans for a shelter for a school building in Wichita, Kansas. The case studies include wind load analyses, detailed shelter design plans, and cost estimates.

Appendixes E and F present the results of missile impact tests on shelter wall sections, and shelter doors and door hardware, respectively.

Appendix G presents design guidance regarding impact protection for wood sheathing.

2 Protection Objectives

As noted in Chapter 1, FEMA has developed standard designs for in-home tornado shelters (or "safe rooms") designed to protect the occupants of a single home during severe wind events. The May 1999 BPAT investigation of the tornadoes in Oklahoma and Kansas made it clear that a severe wind event can cause a large loss of life or a large number of injuries in high-occupancy buildings (e.g., school buildings, hospitals and other critical care facilities, nursing homes, day-care centers, and commercial buildings) and in residential neighborhoods where people do not have access to either in-residence or community shelters. This manual provides design professionals with guidance they need to design community shelters for protection from high-wind events.

NOTE

In May 1999, FEMA provided general criteria for all tornado shelters in the *National Performance Criteria for Tornado Shelters* (NPC). For community shelters, the specific guidance in this manual replaces the general guidance in the May 1999 edition of the NPC. The July 2000 edition of the NPC (available on the World Wide Web at www.fema.gov) now applies only to shelters with fewer than 12 occupants.

The design and planning necessary for extremely high-capacity shelters that may be required for use in large, public use venues such as stadiums or amphitheaters are beyond the scope of this design manual. An owner or operator of such a venue may be guided by concepts presented in this manual, but detailed guidance concerning extremely high-capacity shelters is not provided. The design of such shelters requires attention to issues such as egress and life safety for a number of people that is orders of magnitude greater than that proposed for a shelter designed in accordance with the guidance provided in this manual.

This manual provides guidance regarding issues such as designing and constructing a shelter as a "stand-alone" building; constructing a shelter in a new building; adding a shelter to an existing building; identifying additional wall and roof sections capable of withstanding impacts from windborne debris (missiles); and reconciling prototypical plans with the model building, fire, and life safety codes, as well as emergency operations plans.

2.1 Occupant Safety

This manual presents guidance for the design of engineered shelters that will protect large numbers of people during a high-wind event. Shelters designed by a professional according to the design and performance criteria outlined in this manual (including a design wind speed) are intended to minimize the probability of death and injury during a high-wind event by providing their occupants with near-absolute protection.

WARNING

A shelter designed according to the guidance presented in this manual provides near-absolute protection from death and injury. The shelter, however, may be damaged during a design event. (A design event is determined through the selection of the appropriate design wind speed from the map in Figure 2-2.)

2.1.1 Occupant Risk Levels and Life Safety

The risk of death or injury from tornadoes or hurricanes is not evenly distributed throughout the United States. This manual will guide the reader through the process of identifying the risk of severe winds in a particular location and mitigating that risk. The intent of this manual is not to mandate the construction of shelters for high-wind events, but rather to provide design guidance for persons who wish to design and build such shelters. Levels of risk, and tools for determining the levels of risk, are presented in this chapter.

2.1.2 Design Limitations

The intent of this manual is not to override or replace current codes and standards, but rather to provide important guidance where none has been available. No known building, fire, or life safety code or engineering standard has previously attempted to provide detailed information, guidance, and recommendations concerning the design of tornado or other high-wind shelters intended to provide near-absolute protection. Therefore, the information provided in this manual is the best available at the time this this manual was published. This information will support the design of a shelter that provides near-absolute protection from a specified design wind speed that has been determined to define the wind threat for a given geographic area. Designing and constructing a shelter according to the criteria in this manual does not mean that the shelter will be capable of withstanding every possible high-wind event. The design professional who ultimately designs a shelter should state the shelter design parameters on the project documents.

Examples of actual shelters that have been designed to the criteria presented in this manual are presented in Appendixes C and D.

2.2 Risk Assessment Concepts

The decision to design and construct a shelter can be based on a single factor or on a collection of factors. Single factors are often related to the potential for loss of life or injury (e.g., a hospital that cannot move patients housed in an intensive care unit decides to build a shelter, or shelters, within the hospital; a school decides not to chance fate and constructs a shelter). A collection of factors to be considered in the risk assessment process could include the type of hazard event, probability of event occurrence, severity of the event, probable single and aggregate annual event deaths, shelter costs, and results of computer models that evaluate the **benefits and costs** of the shelter project.

CROSS-REFERENCE

A **benefit/cost** (B/C) analysis model for tornado and hurricane shelters is discussed in Section 2.2.7 and is provided on the CD-ROM inlcuded in Appendix A.

A risk assessment should be performed prior to the design and construction of the shelter. The flowchart in Figure 2-1 will help. The major steps of the risk assessment process—determining the nature, severity, and magnitude of the expected wind event, assessing the potential for death and injury, conducting a site assessment, identifying other influencing factors, and determining shelter costs and benefits—are discussed in Sections 2.2.1 through 2.2.7.

Risk Assessment Flow Chart

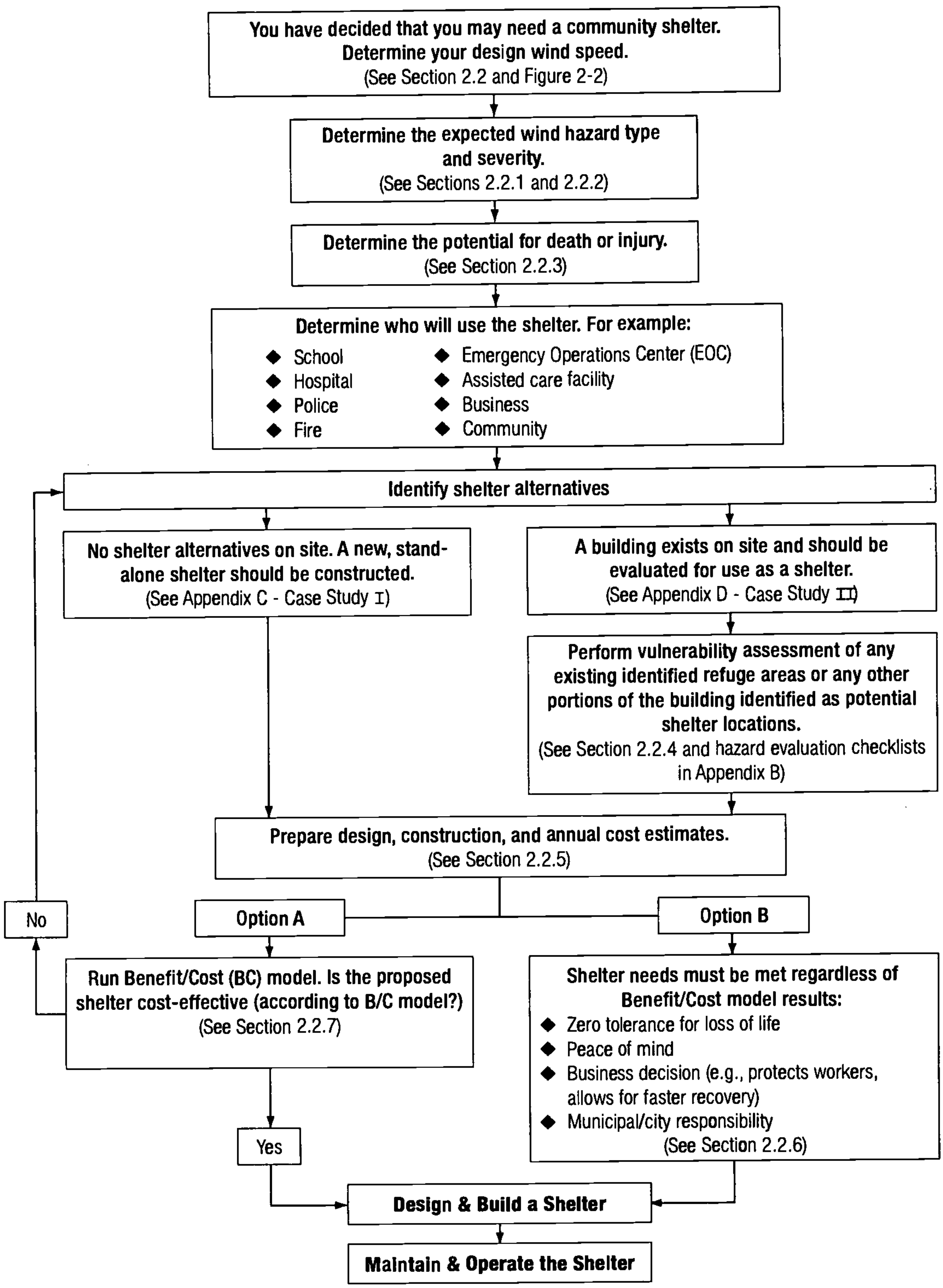


Figure 2-1 Risk assessment flowchart.

NOTE

The wind speeds associated with the Saffir-Simpson Hurricane Scale are recorded as 1-minute sustained winds. Figure 2-2 presents the design wind speeds as 3-second gusts. Therefore, 154-mph winds in a high-end Category 4 Hurricane on the Saffir-Simpson Hurricane Scale are equivalent to 194-mph winds recorded as 3-second gusts. More information on wind speed conversions is provided in Chapter 10.

NOTE

ASCE 7-98 is the national engineering standard for load determination promulgated by the American Society of Civil Engineers (ASCE) and is incorporated by reference into the International Building Code (IBC) and International Residential Code (IRC). The design parameters defined in this manual are for use with the design methodology in ASCE 7-98 except where noted.

2.2.1 Design Wind Speed Map for Risk Assessment and Shelter Design

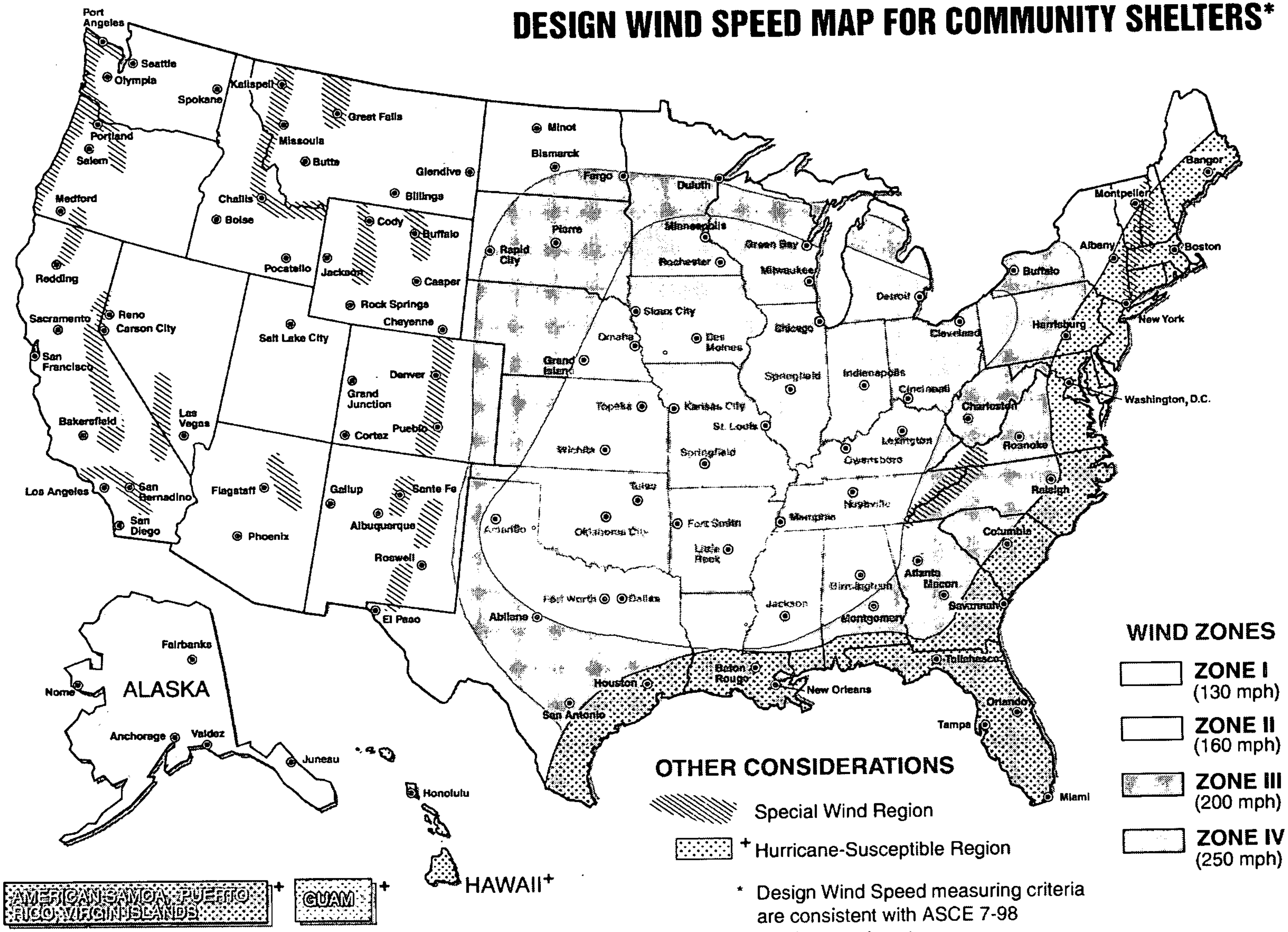
A map of extreme wind speeds was produced for FEMA 320, *Taking Shelter from the Storm; Building a Safe Room Inside Your House*. This design manual uses a revised version of that map, updated and adjusted to reflect the most recent data. The map (Figure 2-2) illustrates the design wind speeds for different geographic regions of the country. The engineer or architect should select the design wind speed for the proposed shelter according to the shelter's geographic location. For example, the design wind speed for a shelter being designed in Wichita, Kansas, is 250 mph, but the design wind speed for a shelter being designed in Rocky Mount, North Carolina, is 200 mph. Designs based on these wind speeds offer similar levels of protection for their respective locations.

Shelters are designed for winds that occur in tornadoes, hurricanes, or thunderstorms. Along the Gulf of Mexico and Atlantic coasts and in the Caribbean and Pacific Islands, hurricane winds control the design (typhoons control the design for the Pacific Islands); in the interior of the United States and Alaska, either tornadoes or thunderstorms are likely to control shelter design.

This change of guidance from FEMA's *National Performance Criteria for Tornado Shelters* is a more refined approach to the design of larger shelters and considers the probability of high winds occurring. The design professional can use the wind speeds shown on the map to design a shelter that provides near-absolute protection for a specific geographic area within the United States. Designing a shelter to protect against the maximum wind speeds possible during the rarest of extreme events is impractical; in addition, such wind speeds are often a matter of debate within the scientific and engineering communities. A design wind speed of 250 mph is considered to be a reasonable maximum design speed for the entire country. Note, however, that Zones I, II, and III have a reduced potential for high-wind events and thus have design wind speeds of 130 mph, 160 mph, and 200 mph, respectively. (Wind speeds stated are 3-second gust, Exposure C, and correspond to an elevation of 33 feet above grade—consistent with ASCE 7-98.)

Wind speed measurements higher than the design wind speeds are frequently reported immediately after an extreme-wind event that are not borne out by careful evaluation. Highly contested wind speed measurements that are outliers in the statistical wind speed data for the United States are not practical design parameters for community shelters. The wind speed measurement devices used and their ability to function properly during a severe event are often questioned. Questions arise about whether the devices were calibrated properly, whether they were rated for the wind speed being measured, and whether they functioned properly (e.g., was the device a hot-wire anemometer that became wet and gave a false reading?). In addition, the wind

DESIGN WIND SPEED MAP FOR COMMUNITY SHELTERS*



* Design Wind Speed measuring criteria are consistent with ASCE 7-98
- 3-second gust
- 33 feet above grade
- Exposure C

Figure 2-2 Design wind speeds for community shelters.

BEST COPY AVAILABLE

32

33

NOTE

It is important to note that FEMA does not intend to revise FEMA 320 to provide designs for in-home shelters that resist wind speeds of less than 250 mph. The 250-mph criterion has resulted in a series of designs that provide a consistent level of protection. In small, in-residence shelters, the wall and roof sections required to resist missile impacts can easily be designed to resist pressures from wind speeds of 250 mph. Any savings that would result from constructing to resist a lower wind speed are insignificant for these small shelters. However, for the longer-span wall and roof sections required for community shelters, wind pressure, rather than missile impact, becomes a much more significant factor in design.

measurement may have been taken high above the ground surface (e.g., measurements taken with Doppler radar that do not reflect wind speeds at the ground surface), or they may have been taken with instruments known to have deficiencies in the severe environments in which the instruments were used.

An example of a recently contested wind speed was the 318-mph wind speed reported by a mobile Doppler-on-Wheels Radar during the May 3, 1999, tornado outbreak. The details of this recorded wind speed do not specify at what elevation between 0 and 200 meters (660 feet) above the ground the speed was measured; therefore, this speed is not considered a reasonable design parameter. What was measured by the Doppler-on-Wheels Radar and exactly at what elevation could not be specified to the satisfaction of many in the engineering and scientific communities. Further, additional effort has been spent validating reported high wind speeds that are currently being contested by the engineering and scientific communities. Resolution of this debate is left to other engineering and scientific teams. The design wind speeds recommended in this manual reflect the judgment of the Project Team of credible wind speeds as estimated by the observed damage to buildings during extreme-wind events.

The development of the wind speed map in Figure 2-2, which considers both tornadoes and hurricanes, is based on historical data. Since 1995, an average of more than 1,200 tornadoes has been reported nationwide each year. Tornadoes are short-lived, are on average less than 500 feet wide, and traverse less than 2,000 feet. Some large tornadoes have been known to cause damage paths that are 3/4 mile wide and traverse many miles; however, tornadoes such as these occur only a few times each year. The land area directly impacted by all tornadoes in a year is relatively small. At present, it is not possible to directly measure wind speeds in a tornado because of its short life. Thus, the data available for tornadoes, intensity, and area of damage are relatively sparse and require special consideration in the probability assessment of wind speeds.

CROSS-REFERENCE

A discussion of the design wind speeds for tornadoes and hurricanes is presented in Chapter 10.

For hurricane wind speeds along the Gulf of Mexico and Atlantic coasts, ASCE 7-98 uses the Monte Carlo numerical simulation procedure to establish design wind speeds. The numerical simulation procedure provides reasonable wind speeds for an annual probability of exceedance of 0.02 (50-year mean recurrence interval [MRI]). For wind speeds with an extremely low probability of occurrence, the current numerical procedure gives unusual answers (e.g., wind speed estimates in Maine are higher than those in Florida). Because the available technology is not precise for low-probability wind speeds, the determination of design wind speeds for hurricanes must be based on the available data and subjective judgment.

Tornadic and hurricane design wind speeds for shelter design are unified to one averaging time of 3 seconds. The resulting 3-second gust speeds are consistent with the reference wind speeds used in ASCE 7-98. Consequently, they can be used in conjunction with ASCE 7-98 to determine wind loads as discussed in Chapter 5.

The wind speeds shown in Figure 2-2 are valid for most regions of the country; however, the Special Wind Regions (e.g., mountainous terrain, river gorges, ocean promontories) shown on the map are susceptible to local effects that may cause substantially higher wind speeds. Mountainous areas often experience localized winds of considerable magnitude. For instance, mountain-induced windstorms in the lee of the Colorado Front Range have been documented at speeds approaching 120 mph. In Boulder, Colorado, straight-line winds in excess of 60 mph are observed about once a year. The frequency and maximum intensity of such high-wind events at higher elevations within Special Wind Regions are likely to be more frequent and even stronger. When the desired shelter location is within one of these regions, or there is reason to believe that the wind speeds on the map do not reflect the local wind climate, the design professional should seek expert advice from a wind engineer or meteorologist.

CROSS-REFERENCE

Tables that show conversions from fastest 1/4-mile speeds and 1-minute sustained speeds to 3-second gust speeds are presented in Chapter 10.

2.2.2 Tornado and Hurricane Histories

A map that shows F3, F4, and F5 tornado occurrence in the United States, based on historical data, is presented in Figure 2-3. The history of tornado occurrence in a given area, alone or with the other factors mentioned in this section on risk assessment, is also an important factor in the decision-making process of whether or not to construct a community shelter for protection against high-wind events. BPAT investigations conducted after the May 3, 1999, tornadoes indicated that buildings can be retrofitted to resist the effects of smaller tornadoes (F0–F2). However, to resist the forces of larger tornadoes and provide near-absolute protection from all tornadoes, engineered shelters are needed.

As noted in Section 2.2.1, the map in Figure 2-2 shows the design wind speeds for the country based on combined tornado and hurricane threats. Figure 2-3 presents the recorded statistical history of tornado occurrence for strong and violent tornadoes (F3, F4, and F5) for one-degree squares (approximately 3,700 square miles) over a 48-year period. It is because of the threat of these strong and violent tornadoes that the design wind speed map shows wind zones with wind speeds up to 250 mph throughout the center of the country. Similar statistics exist for smaller, F1 and F2 tornadoes and for hurricane landfalls from 1900 to 1999. This statistical data group was used to define Zones I–III in Figure 2-2.

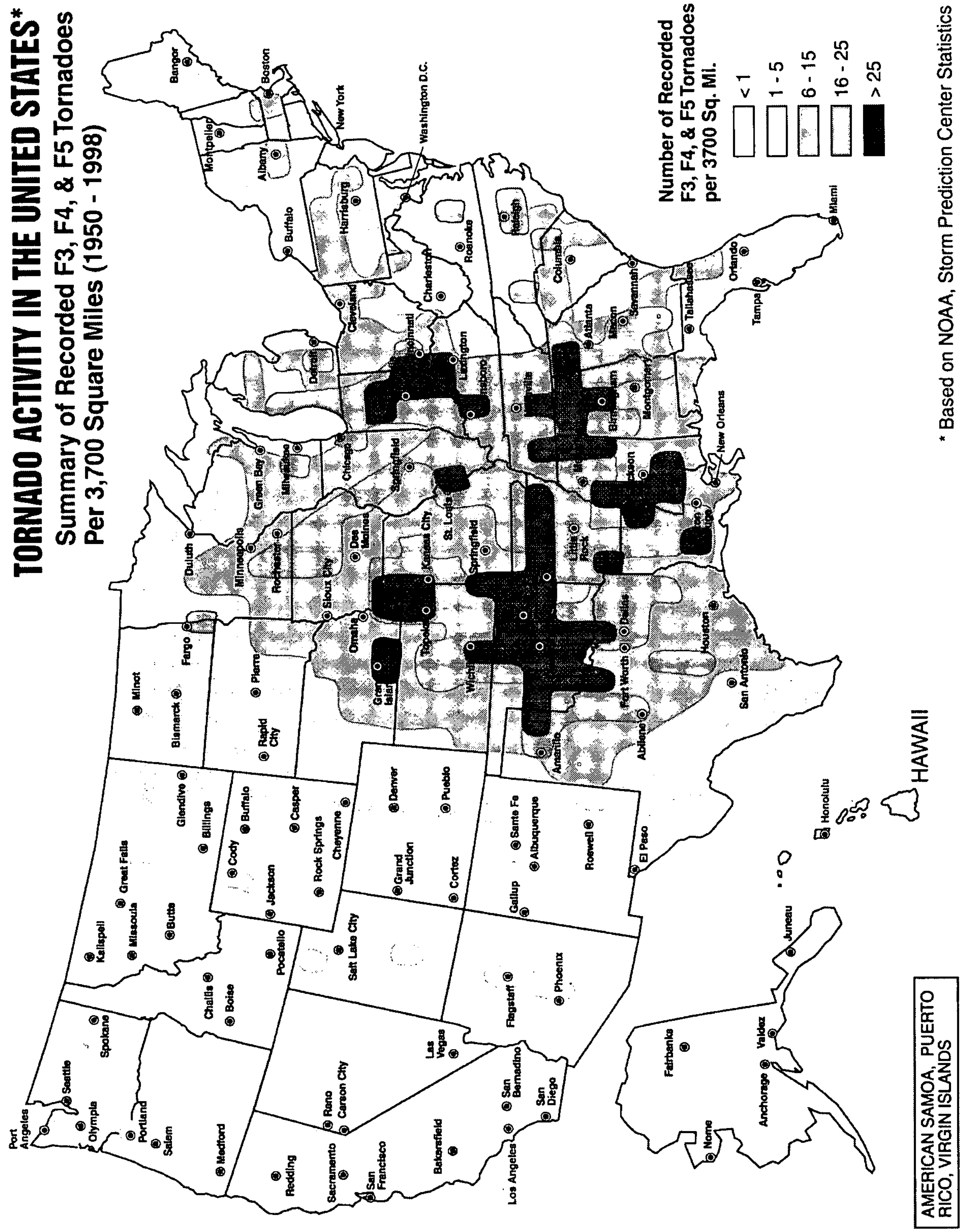


Figure 2-3 Tornado occurrence in the United States based on historical data.

BEST COPY AVAILABLE

36

37

Hurricane histories from 1900 to 1999 were also studied and considered in the preparation of the design wind speed map. These statistics indicate that 79 Category 3, 4, and 5 hurricanes struck the southeast and gulf coast states during that period. These statistics also contributed to the wind zones on Figure 2-2.

The probability data for tornado and hurricane strikes for the United States have been considered in the preparation of the design wind speed map, but are not presented graphically in this manual. However, tornado and hurricane occurrences and their associated probabilities have been included within the benefit/cost model that is discussed in Section 2.2.7 and provided on CD-ROM in Appendix A.

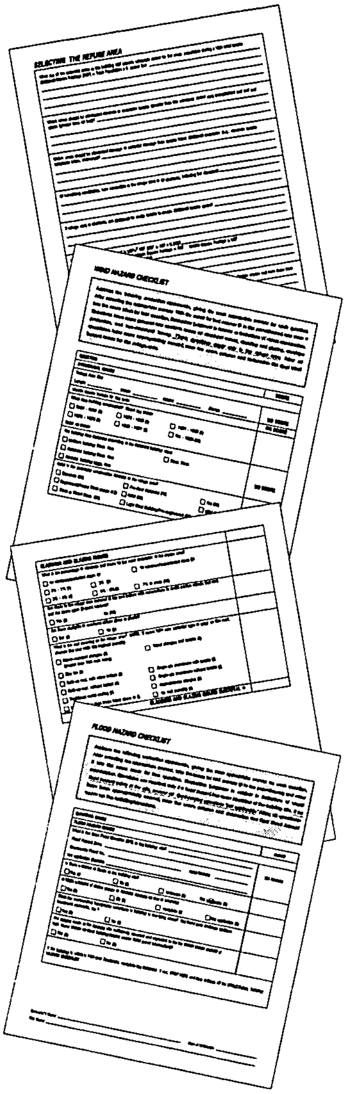
2.2.3 Single and Annual Event Deaths

The owner or user of a potential shelter may decide that, regardless of the probability of a high-wind event occurring at the building site, a certain number of deaths associated with a single event may constitute a reason to construct a shelter. Annualized data on event deaths over specified times may also be a significant factor in the decision to construct or not construct a shelter at a given site.

A convenient source of such data is the World Wide Web. For this project, a significant amount of data was gathered from the Southeast Regional Climate Center (SERCC) and its three-tiered national climate services support program. The partners in this program include the National Climatic Data Center (NCDC at www.ncdc.noaa.gov), the six Regional Climate Centers (RCCs), and the individual and collective State Climate Offices. Private sites also contain significant information regarding deaths, injuries, and costs associated with all types of natural hazard events. The benefit/cost software provided in Appendix A and described in Section 2.2.7 can be used to estimate deaths or injuries both with and without a specially engineered shelter.

2.2.4 Evaluating Existing Areas To Be Used as a Shelter

In inspecting areas of existing buildings that are used as shelter areas, FEMA has found that owners may overlook the safest area of a building. In addition, the safety of a hallway or other shelter area may be overestimated. Evaluating shelter areas in an existing building helps the owner (1) determine whether the safest part of the building is being used as a shelter, (2) identify possible ways to make existing areas safer, and (3) decide whether to design and build a shelter according to the guidance in this manual. A preliminary evaluation may be performed by a design professional or by a potential shelter owner, property owner, emergency manager, building maintenance person, or other interested party provided he or she has a basic knowledge of building sciences and can read and understand building design plans and specifications.



The wind hazard evaluation checklists in Appendix B will help the user assess a building's susceptibility to damage from high-wind events such as tornadoes and severe hurricanes. Although the threat of damage from high-wind events is the predominant focus of the evaluation, additional threats may exist from flood and seismic events; therefore, flood and seismic hazard evaluations should be performed in conjunction with the wind hazard evaluation to assess the multi-hazard threat at the site. Checklists for flood and seismic hazard evaluations are also provided in Appendix B; however, they are designed to support only a generalized evaluation (the wind hazard section of the checklists includes detailed screening processes for the building structure).

The wind, flood, and seismic hazard evaluation checklists in Appendix B may be used for the preliminary assessment. Prior to the design and construction of a shelter, a design professional should perform a more thorough assessment in order to confirm or, as necessary, modify the findings of a preliminary assessment. The checklists in Appendix B can provide a starting point for this more thorough assessment.

An entire building or a section of a building may be designated a potential shelter area. If an existing building is selected for use as a community shelter, the hazard evaluation checklists will help the user identify potential shelter areas within the building and evaluate their vulnerability to natural hazards. The checklist evaluation process will guide the user through the selection of the best shelter areas within the building and focus the evaluation on the critical sections of the building. For example, an evaluator who inspects a portion of a building being considered for use as a shelter should determine whether that portion is structurally independent of the rest of the building, is easily accessible, and contains the required square footage.

The checklists consist of questions pertaining to structural and non-structural characteristics of the area being considered. The questions are designed to identify structural and non-structural vulnerabilities to wind hazards based on typical failure mechanisms. Structural or non-structural deficiencies may be remedied with retrofit designs; however, depending on the type and degree of deficiency, the evaluation may indicate that the existing structure is unsuitable for use as a shelter area. The checklists are not a substitute for a detailed engineering analysis, but they can assist the decision-makers involved with hazard mitigation and emergency management determine whether a building or section of a building has the potential to serve as a shelter.

CROSS-REFERENCE

Guidance concerning the siting of shelters is presented in Chapter 4 of this manual.

The checklists are also used to comparatively rank multiple facilities within a given geographic region that are considered potential shelter sites. A scoring system is included to enable the user to compare performance characteristics at various potential shelter sites and to highlight vulnerabilities. For each question on the checklist, deficiencies and vulnerabilities are assessed penalty points. Therefore, a high score reflects higher hazard vulnerability and a low score reflects lower hazard vulnerability, but only relative to the other buildings considered in the scoring system. There is a minimum possible score for the checklists, but this minimum score will vary, depending on the design wind speed selected from Figure 2-2. Therefore, although a low score is desired, there is no "passing score" or "minimum acceptable score for protection." Again, these checklists help a user determine which area of a building is likely to perform best during a high-wind event and which areas require engineering and retrofit design if they are to provide protection from a tornado, a hurricane, or both.

CROSS-REFERENCE

An additional discussion of probability of high-wind events is presented in Chapter 10.

Electronic versions of the blank checklists and summary score sheet in Appendix B are included on the CD-ROM in Appendix A. Therefore, the user may print additional copies as necessary.

2.2.5 Shelter Costs

Costs for the design, construction, and maintenance of community shelters will vary by location and construction type. As part of the risk assessment plan, budgetary cost estimates (estimates that will be ± 20 percent accurate) should be prepared by the design professional for each proposed shelter alternative.

The most cost-effective means of constructing a shelter at a site is to incorporate the shelter into a new building being planned for construction. The cost to design and construct **hardened** shelter areas within new buildings is much lower than in retrofit situations, in which existing buildings or portions of existing buildings are hardened. For example, in recent FEMA-funded mitigation projects in many midwestern and southeastern states, construction costs for retrofit shelters have been approximately 10–15 percent higher than construction costs for shelters in new buildings. It is important to remember, however, that this increase in cost applies only to a small area of the building (i.e., the area being hardened and not the entire building).

DEFINITION

The term **hardening** refers to the process of modifying the design and construction of a building or part of a building so that it can resist wind pressures and missile impacts during a high-wind event and serve as a shelter. If the hardening is designed by an engineer or architect to meet the criteria in this manual, the hardened area is capable of providing near-absolute protection from the design wind speed (and associated windborne missiles) selected from the map in Figure 2-2.

2.2.6 Other Factors for Constructing a Tornado or Hurricane Shelter

A number of factors can influence the decision-making process. The potential for death or injury discussed in Section 2.2.3 may be a sufficient reason to build a shelter at a given building site. The benefit/cost ratio of constructing a shelter discussed in Section 2.2.7 may be a contributing factor or a requirement of the shelter design process, depending upon the funding source. However, additional factors may be involved in the decision-making process:

- Do the residents feel safe without a shelter?
- Does a business want to provide the protection for its workers?
- Does a shelter allow for faster business recovery after a high-wind event?

- Is the building in question a government-owned building that is required to have a shelter?
- Do zoning ordinances require it?
- Are there insurance benefits?

2.2.7 Benefit/Cost Model

Benefit/cost (B/C) analysis requires knowledge of the probability of occurrence for events of varying magnitude. Appendix A includes a CD-ROM that contains the B/C model software and a user's guide. For tornadoes, the model uses probabilities calculated from data retrieved from the NOAA Storm Prediction Center's Historical Tornado Data Archive. This database contains records of tornado occurrence for all counties in the United States. For hurricanes, the design wind speeds from ASCE 7-98 are used to predict hurricane winds for different probabilities of occurrence for each county. Therefore, the computation of probabilities is geographically based and requires information applicable to specific sites. The purpose of the software is to facilitate the computation of B/C ratios for shelter construction by providing a user-friendly tool for processing the required data.

The model inputs are as follows:

- location, including target county
- project descriptive information (e.g., address, disaster number, project number, project description)
- model run identification
- entire building dimensions
- shelter area
- shelter construction type
- shelter tornado occupancy by hour
- shelter hurricane occupancy by day
- mitigation construction costs
- mitigation maintenance costs
- mitigation useful life and discount rate
- injury and mortality damage functions for each construction type for various wind speeds
- mitigation effectiveness against injury and mortality for various wind speeds
- geographic region around target county for tornado statistics

The model predicts project benefits by determining the monetary savings realized from the proposed mitigation design in terms of the value of avoided deaths of, and injuries to, shelter occupants. The project costs are determined from the cost of construction and maintenance of the proposed mitigation design. To calculate the benefits and costs, the model requires information about the mitigation project being considered and the hazards posed by tornado and hurricane winds. The model has an internal database of tornado hazard data for all counties.

The user selects a region of interest around a target county to provide a statistically significant sample with which to estimate tornado probabilities. The model also contains hurricane wind hazard data for each county, based on the design wind speeds in ASCE 7-98. The hurricane hazard is computed for the target county. With the probabilities known for tornado and hurricane wind hazards, the benefits are calculated from default damage avoidance information contained in the model. Figure 2-4 is a flowchart for the B/C model.

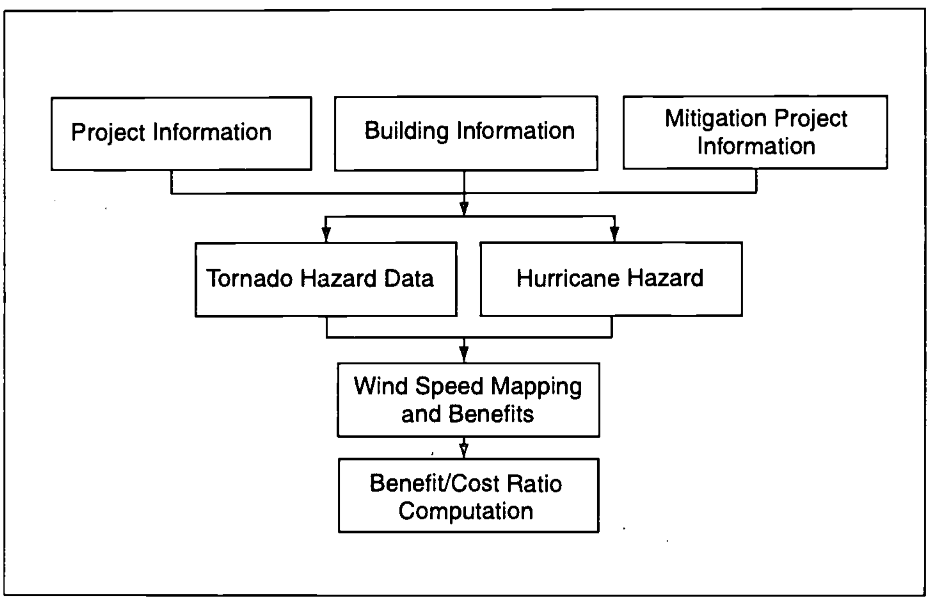


Figure 2-4
Flowchart for the benefit/ cost model.

Details about B/C Model Components

Project Information – Requests data about the project: location, including target county, disaster number, run dates, and other basic information. Most of this information is for identification purposes.

Building Information – Requests dimensions, building type, and occupancy by time of the day for tornado hazards and average occupancy for hurricane hazards.

Mitigation Project Information – Requests description of the proposed mitigation project, construction and maintenance costs, useful life, and mitigation effectiveness against tornadoes and hurricanes. For tornadoes and hurricanes, the mitigation effectiveness is measured as the reduction in deaths and injuries for occupants.

Tornado Hazard Data – Requests the selection of a region around the target county. The tornado hazard data are the probabilities that describe the odds of the building being hit by a tornado at a particular time of the day. Because tornadoes are infrequent events in most locations, it is unlikely that there will be a sufficient number of tornadoes in a particular county to compute probabilities. Therefore, the sample region needs to be expanded to encompass surrounding counties. This region can be selected as a buffer with a selected radius around the target county or the entire state, or manually selected county by county. The model indicates when a sufficient number of counties have been selected. The tornado statistics for the target county and the counties of the sample region were obtained from the National Oceanic and Atmospheric Administration/National Weather Service.

Hurricane Hazard Data - Requires the selection of a target county. Based on ASCE 7-98, each county has a 50-year design wind speed and an adjustment equation for different recurrence intervals. This procedure provides the probability of exceedance for a wide range of wind speeds.

CROSS-REFERENCE

The **Fujita Tornado Scale** and the **Saffir-Simpson Hurricane Scale** are discussed in Chapter 3.

Benefit Computation Based on Wind Speeds – The model uses the tornado and hurricane hazard data to calculate benefits based on avoided deaths and injuries. Each building type provided in the model has an associated injury and mortality rate for specific wind speed ranges, which correspond to **Fujita** tornado damage classes and **Safford-Simpson Hurricane Scale** categories. The user can enter adjustments to these "pre-mitigation" and "post-mitigation" rates for injury and mortality based on the mitigation project design effectiveness. The model uses these pre- and post-mitigation damage rates in conjunction with the tornado and hurricane hazard data to calculate the project benefits.

B/C Ratio Computation – The model calculates benefits and a B/C ratio and prints reports. The model adds the benefits computed (for tornadoes and hurricanes) and discounts them to current value using the Federal discount rate and the useful life of the project. The capital cost of the project and any annual maintenance costs are also converted to current value.

CROSS-REFERENCE

Technical details of the B/C model are discussed in Appendix A.

The development of the model software relied on expert engineering and scientific judgement in a number of areas as described in Appendix A. The model looks at the loss of life and injuries associated with both tornadoes and hurricanes. The assumptions, logic, and methodology used to develop the model are presented along with the users' manual in Appendix A.

3 Characteristics of Tornadoes and Hurricanes

This chapter provides basic information about tornadoes and hurricanes and how they affect the built environment. This information will help the reader better understand how extreme winds damage buildings and the specific guidance provided in Chapters 5, 6, and 7.

3.1 General Wind Effects on Buildings

Building failures occur when winds produce forces on buildings that the buildings were not designed or constructed to withstand. Failures also occur when the breaching of a window or door creates a large opening in the building envelope. These openings allow wind to enter buildings, where it again produces forces that the buildings were not designed to withstand. Other failures may be attributed to poor construction, improper construction techniques, and poor selection of building materials.

Past history and post-disaster investigations have shown that, to a large extent, wind damage to both residential and non-residential buildings is preventable. Mitigation opportunities for property protection have been identified along the periphery of strong and violent tornadoes, in the path of the vortex of weak tornadoes, and within the windfields of most hurricanes. In these areas, damage to property was investigated to determine whether losses could have been minimized through compliance with up-to-date model building codes and engineering standards, and whether construction techniques proven to minimize damage in other wind-prone areas were used. It has been determined that property protection can be improved to resist the effects of smaller tornadoes. This is an important consideration when building owners are considering mitigation because, on average since 1995, F1 and F2 tornadoes account for approximately 80–95 percent of reported tornadoes in any given year (based on NOAA tornado data from 1995 to 1998).

However, for tornadoes classified F3 and larger (see Table 3.1), large areas of buildings cannot be economically strengthened to resist the wind loads. If the building cannot resist the wind loads acting on it, it will fail. However, if the occupants of the building have retreated to a safe, specially designed and constructed shelter area, deaths and injuries will be avoided. Shelters designed and constructed according to the principles in this manual provide a near-absolute level of protection for their occupants.

3.2 Wind-Induced Forces – Tornadoes and Hurricanes

Tornadoes and hurricanes are extremely complex wind events that cause damage ranging from minimal or minor to extensive devastation. It is not the intent of this section to provide a complete and thorough explanation or definition of tornadoes, hurricanes, and the damage associated with each event. However, this section does define basic concepts concerning tornadoes, hurricanes, and their associated damage.

3.2.1 Tornadoes

In a simplified tornado model, there are three regions of tornadic winds:

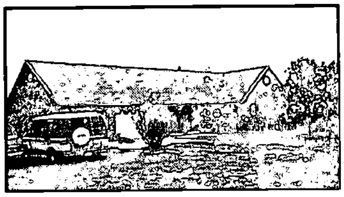
- Near the surface, close to the core or vortex of the tornado. In this region, the winds are complicated and include the peak at-ground wind speeds, but are dominated by the tornado's strong rotation. It is in this region that strong upward motions occur that carry debris upward, as well as around the tornado.
- Near the surface, away from the tornado's vortex. In this region, the flow is a combination of the tornado's rotation, inflow into the tornado, and the background wind. The importance of the rotational winds as compared to the inflow winds decreases with distance from the tornado's vortex. The flow in this region is extremely complicated. The strongest winds are typically concentrated into relatively narrow swaths of strong spiraling inflow rather than a uniform flow into the tornado's vortex circulation.
- Above the surface, typically above the tops of most buildings. In this region, the flow tends to become nearly circular.

In a tornado, the diameter of the core or vortex circulation can change with time, so it is impossible to say precisely where one region of the tornado's flow ends and another begins. Also, the visible funnel cloud associated with and typically labeled the vortex of a tornado is not always the edge of the strong extreme winds. Rather, the visible funnel cloud boundary is determined by the temperature and moisture content of the tornado's inflowing air. The highest wind speeds in a tornado occur at a radius measured from the tornado vortex center that can be larger than the edge of the visible funnel cloud's radius. It is important to remember that a tornado's wind speeds cannot be determined solely from its appearance.

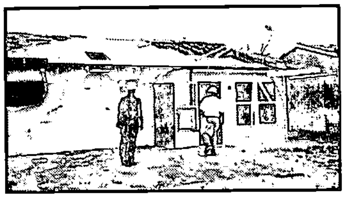
Tornadoes are commonly categorized according to the Fujita Scale, which was created by the late Dr. Tetsuya Theodore Fujita, University of Chicago. The Fujita Scale (see Table 3.1) categorizes tornado severity by damage observed, not by recorded wind speeds. Ranges of wind speeds have been associated with the damage descriptions of the Fujita Scale, but their accuracy has been called into question by both the wind engineering and meteorological communities, especially the ranges for the higher end (F4 and F5) of the scale. The wind speeds are estimates that are intended to represent the observed

Table 3.1
The Fujita Scale

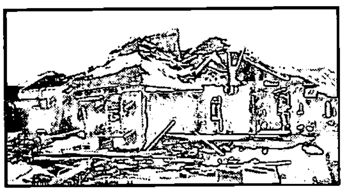
Category / Typical Damage



F0 Light: Chimneys are damaged, tree branches are broken, shallow-rooted trees are toppled.

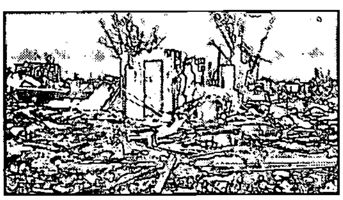


F1 Moderate: Roof surfaces are peeled off, windows are broken, some tree trunks are snapped, unanchored manufactured homes are overturned, attached garages may be destroyed.

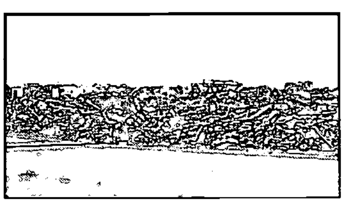


F2 Considerable: Roof structures are damaged, manufactured homes are destroyed, debris becomes airborne (missiles are generated), large trees are snapped or uprooted.

F3 Severe: Roofs and some walls are torn from structures, some small buildings are destroyed, unreinforced masonry buildings are destroyed, most trees in forest are uprooted.



F4 Devastating: Well-constructed houses are destroyed, other houses are lifted from foundations and blown some distance, cars are blown some distance, large debris becomes airborne.



F5 Incredible: Strong frame houses are lifted from foundations, reinforced concrete structures are damaged, automobile-sized debris becomes airborne, trees are completely debarked.

F0, F1, F2, F3, F4, F5 IMAGES: FEMA

damage. They are not calibrated wind speeds, nor do they account for variability in the design and construction of buildings.

Tornado damage to buildings can occur as a result of three types of forces:

1. wind-induced forces
2. forces induced by changes in atmospheric pressure
3. forces induced by debris impact

Forces due to tornadic and hurricane winds are discussed in detail later in this chapter. Guidance on the calculation of these forces is provided in Chapter 5.

The atmospheric pressure in the center of the tornado vortex is lower than the ambient atmospheric pressure. When a tornado vortex passes over a building, the outside pressure is lower than the ambient pressure inside the building. This atmospheric pressure change (APC) in a tornado may cause outward-acting pressures on all surfaces of the building. If there are sufficient openings in the building, air flowing through the openings will equalize the inside and outside atmospheric pressures, and the APC-induced forces will not be a problem. However, it should be noted that openings in the building envelope also allow wind to enter the building and cause internal pressures in addition to wind-induced aerodynamic external pressures (see Section 5.3.1).

Maximum APC occurs in the center of a tornado vortex where winds are assumed to be zero. A simple tornado vortex model suggests that, at the radius of the maximum winds, APC is one-half of the maximum value. Thus, for tornado loadings, two situations of the state of the building should be considered: (1) sealed building, or (2) vented building (i.e., a building with openings). For a sealed building, the maximum design pressure occurs when wind-induced aerodynamic pressure is combined with one-half APC-induced pressure. For a vented building, the maximum design pressure occurs when wind-induced aerodynamic pressure is combined with wind-induced internal pressure. See Chapter 5 for design guidance regarding the effects of APC.

Tornadic winds tend to lift and accelerate debris (missiles) consisting of roof gravel, sheet metal, tree branches, broken building components, and other items. This debris can impact building surfaces and perforate them. Large debris, such as automobiles, tends to tumble along the ground. The impact of this debris can cause significant damage to wall and roof components. The debris impact and the high winds result from the same storm. However, each debris impact affects the structure for an extremely short duration, probably less than 1 second. For this reason, the highest wind load and the highest impact load are not considered likely to occur at precisely the same time. Design guidance for the impact of debris is presented in Chapter 6.

3.2.2 Hurricanes

Hurricanes are one of the most destructive forces of nature on earth. Views of hurricanes from satellites thousands of miles above the earth show the power of these very large, but tightly coiled weather systems. A hurricane is a type of tropical cyclone, the general term for all circulating weather systems (counterclockwise in the Northern Hemisphere) originating over tropical waters. Tropical cyclones are classified as follows:

- **Tropical Depression** – An organized system of clouds and thunderstorms with a defined circulation and maximum sustained winds of 38 mph or less.
- **Tropical Storm** – An organized system of strong thunderstorms with a defined circulation and maximum sustained winds of 39 to 73 mph.
- **Hurricane** – An intense tropical weather system with a well-defined circulation and sustained winds of 74 mph or higher. In the western Pacific, hurricanes are called "typhoons," and similar storms in the Indian Ocean are called "cyclones."

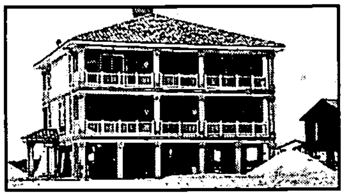
Hurricanes that affect the U.S. mainland are products of the Tropical Ocean (Atlantic Ocean, Caribbean Sea, or Gulf of Mexico) and the atmosphere. Powered by heat from the sea, they are steered by the easterly trade winds and the temperate westerlies as well as by their own ferocious energy. Around their core, winds grow with great velocity, generating violent seas. Moving ashore, they sweep the ocean inward (storm surge) while spawning tornadoes, downbursts, and straight-line winds, and producing torrential rains and floods.

Hurricanes are categorized according to the Saffir-Simpson Hurricane Scale (see Table 3.2), which was designed in the early 1970s by Herbert Saffir, a consulting engineer in Coral Gables, Florida, and Robert Simpson, who was then director of the National Hurricane Center. The Saffir-Simpson Hurricane Scale is used by the National Weather Service to estimate the potential property damage and flooding expected along the coast from a hurricane landfall. The scale is a 1–5 rating based on the hurricane's current intensity. Wind speed and barometric pressure are the determining factors in the scale. Storm surge is not a determining factor, because storm surge values are highly dependent on the slope of the continental shelf in the landfall region.

Recently, there has been increased recognition of the fact that wind speed, storm surge, and inland rainfall are not necessarily coupled. There is growing interest in classifying hurricanes by separate scales according to the risks associated with each of these threats.

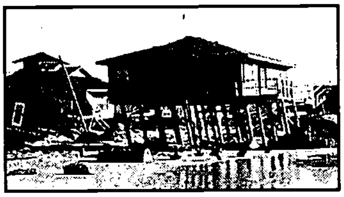
Table 3.2
The Saffir-Simpson Hurricane Scale

Category / Typical Damage

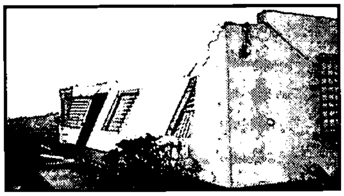


C1 Minimal: Damage is done primarily to shrubbery and trees, unanchored manufactured homes are damaged, some signs are damaged, no real damage is done to structures on permanent foundations.

C2 Moderate: Some trees are toppled, some roof coverings are damaged, major damage is done to manufactured homes.



C3 Extensive Damage: Large trees are toppled, some structural damage is done to roofs, manufactured homes are destroyed, structural damage is done to small homes and utility buildings.



C4 Extreme Damage: Extensive damage is done to roofs, windows, and doors; roof systems on small buildings completely fail; some curtain walls fail.

C5 Catastrophic Damage: Roof damage is considerable and widespread, window and door damage is severe, there are extensive glass failures, some buildings fail completely.

C1, C2, C3, C4 IMAGES: FEMA
C5 IMAGE COURTESY OF NOAA, HISTORICAL DATA COLLECTION

3.2.3 Typhoons

Typhoons affect the Pacific Islands (Hawaii, Guam, and American Samoa) and, like hurricanes, can generate high winds, flooding, high-velocity flows, damaging waves, significant erosion, and heavy rainfall. Historically, typhoons have been classified according to strength as either typhoons (storms with less than 150 mph winds) or super typhoons (storms with wind speeds of 150 mph or greater) rather than by the Saffir-Simpson Hurricane Scale. For the purposes of this manual, the guidance provided for hurricanes applies to areas threatened by typhoons.

3.3 Effects of Extreme Winds and Tornado Forces

Wind-induced damage to residential and commercial buildings indicates that extreme winds moving around buildings generate loads on building surfaces that can lead to the total failure of a building. In addition, internal pressurization due to a sudden breach of the building envelope (the failure of the building exterior) is also a major contributor to poor building performance under severe wind loading conditions. If a building is constructed with a **continuous load path**, the building's ability to survive during a design event will be improved, even if a portion of the building envelope fails. This section discusses topics related to wind, wind pressures acting on buildings, and windborne debris (missiles). The importance of a continuous load path within a building or structure is discussed in Section 5.5.

CROSS-REFERENCE

Section 5.5 presents detailed information about **continuous load paths.** A continuous load path is required in a shelter in order for the shelter to resist the wind and wind pressures described in this section.

3.3.1 Forces Generated by the Design Wind Speed

The design wind speed for construction of a community shelter should be determined from Figure 2-2. When calculating the wind pressures from the design wind speed, the designer should not consider the effects of the other parts of the building that may normally reduce wind pressures on the shelter. The designer should also ensure either that the destruction of the non-shelter parts of the building does not put additional loads on the shelter or that the shelter is designed for these additional loads.

CROSS-REFERENCE

The **design wind speed** for the proposed shelter is selected from Figure 2-2.

The design wind speed is used to predict forces on both the main wind force resisting system (MWFRS) and on the exterior surfaces of the buildings—components and cladding (C&C). The MWFRS is the structural system of the building or shelter that works to transfer wind loads to the ground and includes structural members such as roof systems (including diaphragms), frames, cross bracing, and loadbearing walls. C&C elements include wall and roof members (e.g., joists, purlins, studs), windows, doors, fascia, fasteners, siding, soffits, parapets, chimneys, and roof overhangs. C&C elements receive wind loads directly and transfer the loads to other components or to the MWFRS.

The effects of wind on buildings can be summarized as follows:

- Inward-acting, or positive, pressures act on windward walls and windward surfaces of steep-sloped roofs.
- Outward-acting, or negative pressures act on leeward walls, side walls, leeward surfaces of steep-sloped roofs, and all roof surfaces for low-sloped roofs or steep-sloped roofs when winds are parallel to the ridge.
- Airflow separates from building surfaces at sharp edges and at points where the building geometry changes.

- Localized suction or negative pressures at eaves, ridges, edges, and the corners of roofs and walls are caused by turbulence and flow separation. These pressures affect loads on C&C.
- Windows, doors, and other openings are subjected to wind pressures and the impact of windborne debris (missiles). If these openings fail (are breached) because of either wind pressure or windborne debris, then the entire structure becomes subject to wind pressures that can be twice as great as those that would result if the building remained fully enclosed.

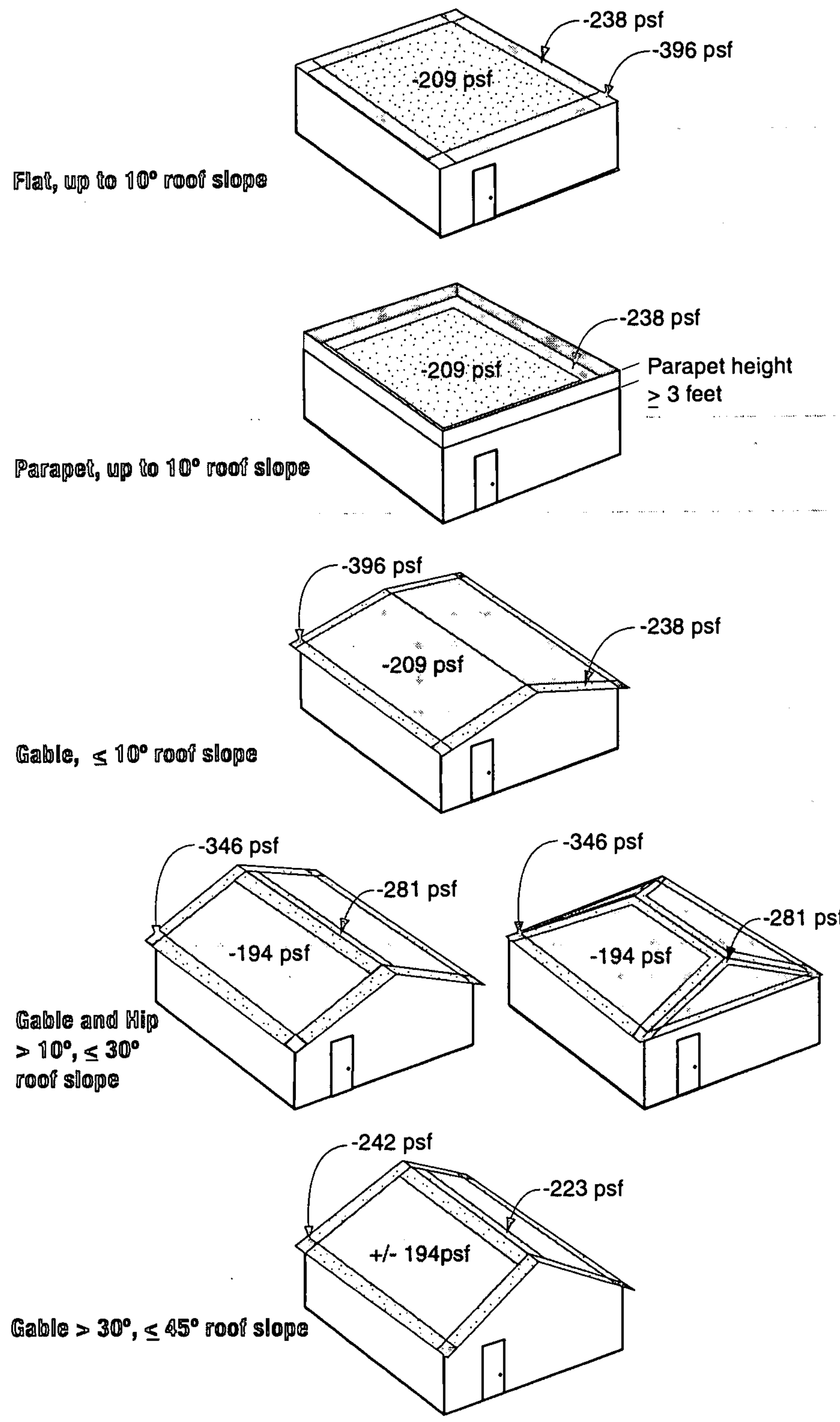
High winds are capable of imposing large lateral (horizontal) and uplift (vertical) forces on buildings. The strength of the building's structural frame, connections, and envelope determine the ability of the building to withstand the effects of these forces.

Wind loads are influenced by the location of the building site (the general roughness of the surrounding terrain, including open, built-up, and forested areas, can affect wind speed), height of the building (wind pressures increase with height above ground, or the building may be higher than surrounding vegetation and structures and therefore more exposed), surrounding topography (land surface elevations can create a speedup effect), and the configuration of the building.

Roof shape plays a significant role in roof performance, both structurally and with respect to the magnitude of the wind loads. Compared to other types of roofs, hip roofs generally perform better in high winds because they have fewer sharp corners and because their construction makes them inherently more structurally stable. Gable-end roofs require extensive detailing to properly transfer lateral loads acting against the gable-end wall into the structure. Steeply pitched roofs usually perform better than flat roofs because uplift on the windward roof slopes is either reduced or eliminated.

Figure 3-1 illustrates the effects of roof geometry on wind loads. Notice that a 3-foot parapet around a roof does not have elevated roof pressures at the corners and that a gable roof with a roof pitch of greater than 30 degrees produces the lowest leeward and corner pressures. The highest roof pitches tested are 45 degrees (12 on 12 pitch) because few roofs have steeper pitches than 45 degrees and few data are available for higher slopes.

Wind loads and the impact of windborne debris are both capable of damaging a building envelope. Post-disaster investigations of wind-damaged buildings have shown that many building failures begin because a component or a segment of cladding is blown off the building, allowing wind and rain to rapidly enter the building. An opening on the windward face of the building can also lead to a failure by allowing positive pressures to occur that, in

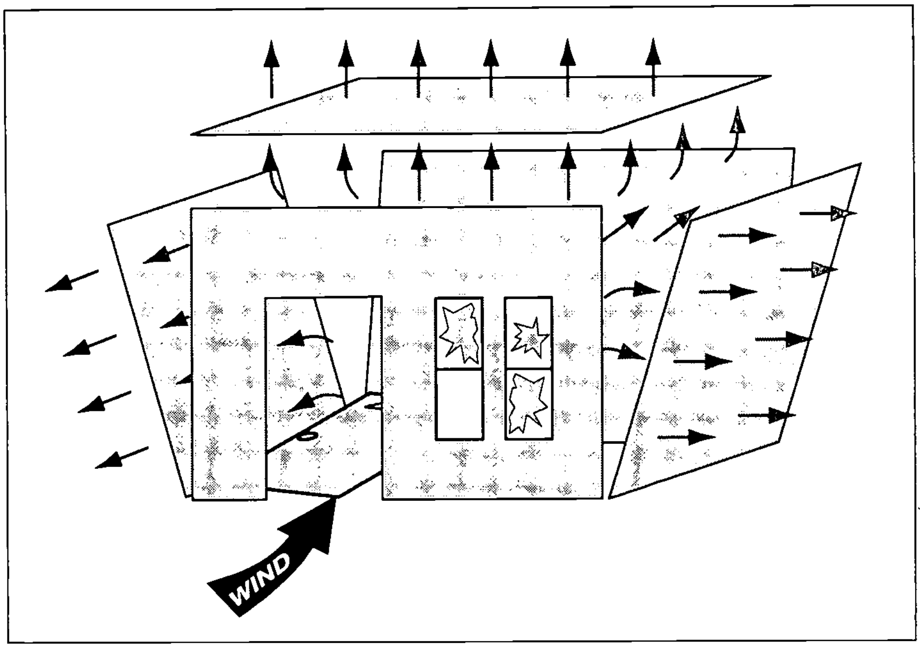


NOTE: Design pressures all assume the same basic wind speed (250 mph 3-second peak gust), Exposure C, and mean roof height.

Figure 3-1
Calculated pressures (based on ASCE 7-98 C&C equations) acting on a typical shelter. This figure illustrates the different roof pressures that result for the same building and wind speed as the roof shape is varied. For the calculation of the loads from these pressures, the shelter was assumed to be a 50-foot x 75-foot rectangular building with a constant mean roof height of 12 feet. Note: These loads do not include any additional loads from internal pressurization resulting from either a vented or breached building envelope.

conjunction with negative external pressures, can "blow the building apart." Figure 3-2 depicts the forces that act on a structure when an opening exists in the windward wall.

Figure 3-2
Internal pressurization and resulting building failure due to design winds entering an opening in the windward wall.



The magnitude of internal pressures depends on whether the building is "enclosed," "partially enclosed," or "open" as defined by ASCE 7-98. The internal pressures in a building are increased as a building is changed from an "enclosed" to a "partially enclosed" building. The design criteria presented in Chapter 5 recommend that shelter design be based on the partially enclosed internal pressures. The walls and the roof of the shelter and connections between the components should be designed for the largest possible combination of internal and external pressures. This design concept is in keeping with using a conservative approach because of the life safety issues involved in shelter design.

3.3.2 Building Failure Modes – Elements, Connections, and Materials

The wind forces described in the previous section will act on a building as both inward-acting and outward-acting forces. The direction and magnitude of the forces are governed by the direction of the wind, location of the building, height and shape of the building, and other conditions that are based on the terrain surrounding the building. Chapter 5 of this manual and Section 6 of ASCE 7-98 provide information on calculating the direction and magnitude of the wind forces acting on a building once the design wind speed and openings in the building envelope have been established. Winds moving around a building or structure may cause sliding, overturning, racking, and component failures.

Building failures can be independently categorized by one or a combination of the four failure modes illustrated in Figure 3-3. A sliding failure occurs when wind forces move a building laterally off its foundation. An overturning failure occurs when a combination of the lateral and vertical wind forces cause the entire building to rotate about one of its sides. A racking failure occurs when the building's structural system fails laterally, but the building typically remains connected to the foundation system. A component failure, the most common failure seen during high-wind events (and typically a contributing failure to the first three failure modes listed), may be caused by wind pressures or windborne debris (missile) impacts. Component failures may be either full-system failures or individual element failures.

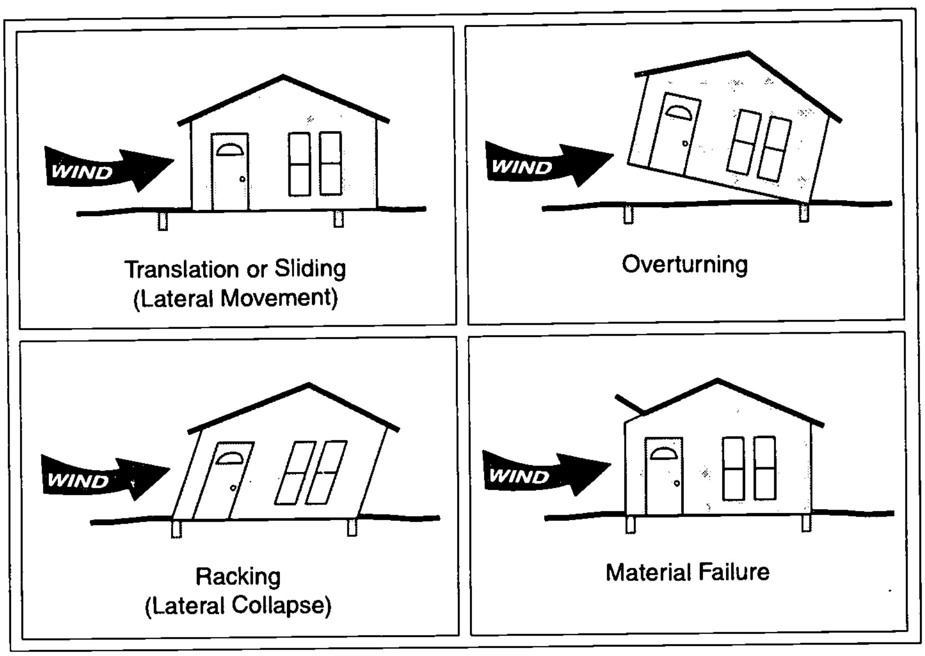


Figure 3-3
Forces on a building due to wind moving around the structure.

Most buildings are designed as enclosed structures with no large or dominant openings that allow the inside of the building to experience internal pressurization from a wind event. However, under strong wind conditions, a breach in the building envelope due to broken windows, failed entry doors, or failed large overhead doors may cause a significant increase in the net wind loads acting on building components such as walls and the roof structure . In such cases, the increase in wind load may cause a partial failure or propagate into a total failure of the primary structural system. Uplift or downward force (depending on roof pitch and wind direction) may act upon the roof of the building and cause overturning, racking, or failure of components.

CROSS-REFERENCE

Chapter 6 presents additional information about cyclic loading for missile impact protection and for code compliance in specific regions of the country.

3.3.3 Cyclic Loading

Both tornadoes and hurricanes have unsteady wind patterns within their circular wind fields. These effects cause cyclic loading on buildings. Tornadoes, however, generally pass over a site in a very short time. Wind experts believe that the cyclic periods of wind loads in tornadoes are short and less frequent than those in hurricanes. Thus, designing tornado shelters for cyclic loads is not recommended.

Hurricane winds typically impact a site for a much longer time. This can result in many repetitive cycles close to the peak loads. Failures in the roof system itself, and of roof-to-wall, wall-to-wall, wall-to-floor, and wall/floor to foundation connections, can occur under repetitive loads. Cyclic loads become particularly important when either the structure or a component is flexible or when the fastening system receives repetitive loading. When cyclic loads are to be considered, designers are advised to review loading cycles given in the ASTM Standard E 1996 or to use allowable stresses below the endurance limit of materials or connections. Structural connections of heavy steel and reinforced concrete and masonry construction, where the structural system is rigid, are likely to resist hurricane cyclic loads.

3.3.4 Windborne Debris – Missiles

Tornadoes and hurricanes produce large amounts of debris that become airborne. This windborne debris (missiles) may kill or injure persons unable to take refuge and may also perforate the envelope and other components of any conventional building in the path of the debris. The size, mass, and speed of missiles in tornadoes or hurricanes varies widely. Only a few direct measurements of debris velocity have been made. Such measurements require using photogrammetric techniques to analyze movies of tornadoes that contain identifiable debris. For this reason, the choice of the missiles that a shelter must withstand is somewhat subjective. From over 30 years of post-disaster investigations after tornadoes and hurricanes, the Wind Engineering Research Center at Texas Tech University (TTU) concluded that the missile most likely to perforate building components is a wood 2x4 member, weighing up to 15 lb. Other, larger airborne missiles do occur; larger objects, such as cars, can be moved across the ground or, in extreme winds, they can be tumbled, but they are less likely than smaller missiles to perforate building elements. Following the Oklahoma and Kansas tornado outbreaks of May 3, 1999, both FEMA and TTU investigated tornado damage and debris fields and concluded that the 15-lb 2x4 missile was reasonable for shelter design.

3.3.5 Resistance to Missile Impact

Relationships between wind speed and missile speed have been calculated. For a 250-mph wind speed, the highest design wind speed considered necessary for shelter design, the horizontal speed of a 15-lb missile is calculated to be 100 mph based on a simulation program developed at TTU. The vertical speed of a falling wood 2x4 is considered to be two-thirds the horizontal missile speed. Although the probability is small that the missile will travel without rotation, pitch, or yaw and that it will strike perpendicular to the surface, these worst case conditions are assumed in design and testing for missile perforation resistance. Therefore, the missile design criterion for all wind zones is a 15-lb wood 2x4 traveling without pitch or yaw at 100 mph and striking perpendicular to the surface.

After a structure is designed to meet wind load requirements, its roof, walls, doors, and windows must be checked for resistance to missile impacts. Table 3.3 summarizes missile impact speeds based on previous research for the design wind speeds presented in Figure 2-2.

Table 3.3
Summary of Previous Research on Probable Missile Speeds for a 15-lb Wood 2x4 Missile as Associated With the Design Wind Speeds From Figure 2-2

WIND ZONE	PREDOMINANT WIND TYPE	DESIGN WIND SPEED	MISSILE SPEED AND DIRECTION
I	Tornado & Hurricane	130 mph	80 mph Horizontal 53 mph Vertical
II	Tornado & Hurricane	160 mph	84 mph Horizontal 56 mph Vertical
III	Tornado	200 mph	90 mph Horizontal 60 mph Vertical
IV	Tornado	250 mph	100 mph Horizontal 67 mph Vertical

The structural integrity necessary to withstand wind forces for small residential shelters can be provided with materials common to residential construction. The major challenge in designing small shelters is, then, to protect against missile perforation. A number of designs for safe rooms capable of withstanding a 250-mph design wind are presented in FEMA 320. For larger shelters, the design challenge shifts to providing the structural integrity necessary to resist wind loads. Walls designed with reinforced concrete or reinforced masonry to carry extreme wind loads will normally prevent perforation by flying debris.

CROSS-REFERENCE

Design guidance for **missile impact** resistance of doors, windows, and other openings is provided in Chapter 6.

The roof, wall sections, and coverings that protect any openings in a shelter should be able to resist **missile impacts**. The limited testing performed at missile speeds lower than the 100-mph impact speed (90, 84, and 80 mph) does not provide enough conclusive data or result in cost savings great enough to justify varying the missile impact criterion presented in this manual. Therefore, the 100-mph missile speed is used in this manual for missile impact resistance for Wind Zones I–IV.

Doors, and sometimes windows, are required for some shelters. However, doors and other openings are vulnerable to damage and failure from missile impact. Large doors with quick-release hardware (required in public buildings) and windows present challenges to the designer. Design guidance for doors and windows is given in Chapter 6.

3.3.6 Falling Debris and Other Impacts

The location of the shelter has an influence on the type of debris that may impact or fall on the shelter. For residential structures, the largest debris generally consists of wood framing members. In larger buildings, other failed building components, such as steel joists, pre-cast concrete members, or rooftop-mounted equipment, may fall on or impact the shelter. Chapter 4 discusses how to minimize the effects of falling debris and other large object impacts by choosing the most appropriate location for a shelter at any given site. Chapter 6 presents design approaches for protecting against these other impacts through engineering design and guidance that are supported by the results of testing.

4 Shelter Types, Location, and Siting Concepts

A community shelter either will be used solely as a shelter or will have multiple purposes, uses, or occupancies. This chapter discusses community shelter design concepts that relate to the type of shelter being designed and where it may be located. This chapter also discusses how shelter use (either single or multiple) may affect the type of shelter selected and the location of that shelter on a particular site.

4.1 Shelter Types

This manual provides design guidance on two types of shelters:

- stand-alone shelters: shelters that are separate buildings
- internal shelters: shelter areas that are within or part of a larger building, but that have been designed to be structurally independent.

This is not meant to imply that these are the only two types of shelters that should be considered. Other shelter options, such as groups of smaller, often proprietary shelter systems, may be appropriate for residential communities, hospitals, schools, or at places of business. It is not possible to provide guidance concerning all sheltering options for all shelter locations. The guidance provided in this manual for stand-alone and internal shelters, including the design criteria, may be applied to other shelter options. If other shelter systems and types of shelters are designed to meet the criteria in this manual, they should be capable of providing near-absolute protection as well.

The guidance provided in this manual is for the design and construction of **new** shelters, not for the addition of shelters to existing buildings (i.e., retrofitting). Because of the variety of structural types and the number of different configurations of existing buildings, only a limited amount of guidance is provided on modifying existing buildings to create a shelter where none existed previously. However, a design professional engaged in a shelter retrofitting project should be able to use the guidance in this manual to determine the risk at the site and calculate the loads acting on the building. In addition, the checklists in Appendix B and information presented in the case studies in Appendixes C and D may be helpful in a shelter retrofitting project.

NOTE

This manual provides guidance for the design and construction of new shelters. The design professional performing retrofit work on existing buildings should apply the new design guidance presented in this manual to the retrofit design.

4.1.1 Stand-Alone Shelters

The results of the risk and site assessments discussed in Chapter 2 may show that the best solution to providing protection for large numbers of people is to build a new, separate (i.e., stand-alone) building specifically designed and constructed to serve as a tornado or hurricane shelter.

Potential advantages of a stand-alone shelter include the following:

- The shelter may be sited away from potential debris hazards.
- The shelter will be structurally separate from any building and therefore not vulnerable to being weakened if part of an adjacent structure collapses.
- The shelter does not need to be integrated into an existing building design.

Case Study I (see Appendix C) shows the calculated wind loads for a shelter in Zone III (200 mph) and how the design requirements were met for a stand-alone shelter. This shelter was designed to serve communities in North Carolina that housed families displaced by flooding caused by Hurricane Floyd.

CROSS-REFERENCE

Tornado Refuge Evaluation Checklists are discussed in Chapter 2 and presented in Appendix B. A risk assessment plan that uses these checklists can help determine which type of shelter is best suited to a given site.

4.1.2 Internal Shelters

The results of the risk and site assessments presented in Chapter 2 may show that a specifically designed and constructed shelter area within or connected to a building is a more attractive alternative than a stand-alone shelter, especially when the shelter is to be used by the occupants of the building. This section concentrates on design considerations that are important for internal shelters.

Potential advantages of an internal shelter include the following:

- A shelter that is partially shielded by the surrounding building may not experience the full force of the tornado or hurricane wind. (Note, however, that any protection provided by the surrounding building should not be considered in the shelter design.)
- A shelter designed to be within a new building may be located in an area of the building that the building occupants can reach quickly, easily, and without having to go outside.
- Incorporating the shelter into a planned renovation or building project may reduce the shelter cost.

Case Study II (see Appendix D) shows the calculated wind loads for a shelter in Zone IV (250 mph) and how the design requirements were met for a shelter connected to an existing building. This shelter was designed for a school in Wichita, Kansas, and replaced a portion of the school building that was damaged by the tornadoes of May 3, 1999.

4.2 Single-Use and Multi-Use Shelters

A stand-alone or internal shelter may serve as a shelter only, or it may have multiple uses—for example, a multi-use shelter at a school could also function as a classroom, lunchroom, or laboratory; a multi-use shelter intended to serve a manufactured housing community or single-family-home subdivision could also function as a community center. The decision to design and construct a single-use or a multi-use shelter will likely be made by the prospective client or the owner of the shelter. To help the designer respond to non-engineering and non-architectural needs of shelter owners, this section discusses how shelter use may affect the type of shelter selected.

4.2.1 Single-Use Shelters

Single-use shelters are, as the name implies, used only in the event of a natural hazard event. One advantage of single-use shelters is a potentially simplified design that may be readily accepted by a local building official or fire marshal. Single-use shelters typically have simplified electrical and mechanical systems because they are not required to provide normal daily accommodations for people. Single-use shelters are always ready for occupants and will not be cluttered with furnishings and storage items, which is a concern with multi-use shelters. Simplified, single-use shelters may have a lower total cost of construction than multi-use shelters. Examples of single-use shelters were observed during the BPAT investigation of the May 3, 1999, tornadoes, primarily in residential communities (FEMA 1999a). Small, single-use shelters were used in residential areas with a shelter-to-house ratio of 1:1 or ratios of up to 1:4. One example of a large, single-use community shelter was observed in a manufactured housing park in Wichita, Kansas.

The cost of building a single-use shelter is much higher than the additional cost of including shelter protection in a multi-use room. Existing maintenance plans will usually consider multi-use rooms, but single-use shelters can be expected to require an additional annual maintenance cost.

4.2.2 Multi-Use Shelters

The ability to use a shelter for more than one purpose often makes a multi-use stand-alone or internal shelter appealing to a shelter owner or operator. Multi-use shelters also allow immediate return on investment for owners/operators; the shelter space is used for daily business when the shelter is not being used during a tornado or hurricane. Hospitals, assisted living facilities, and special needs centers would benefit from multi-use internal shelters, such as hardened intensive care units or surgical suites. Internal multi-use shelters in these types of facilities allow optimization of space while providing near-absolute protection with easy access for non-ambulatory persons. In new buildings being designed and constructed, recent FEMA-sponsored projects have indicated that the construction cost of hardening a small area or room in a building is 10–25 percent higher than the construction cost for a non-hardened version of the same area or room.

BPAT investigations of the May 3, 1999, tornadoes, as well as investigations conducted after numerous hurricanes in the 1990s, found many examples of multi-use areas designed and retrofitted for use as shelters, such as the following:

- in school buildings – cafeterias, classrooms, hallways, music rooms, and laboratories
- in public and private buildings – cafeterias/lunchrooms, hallways, and bathrooms (see Figure 4-1)
- in hospitals – lunchrooms, hallways, and surgical suites

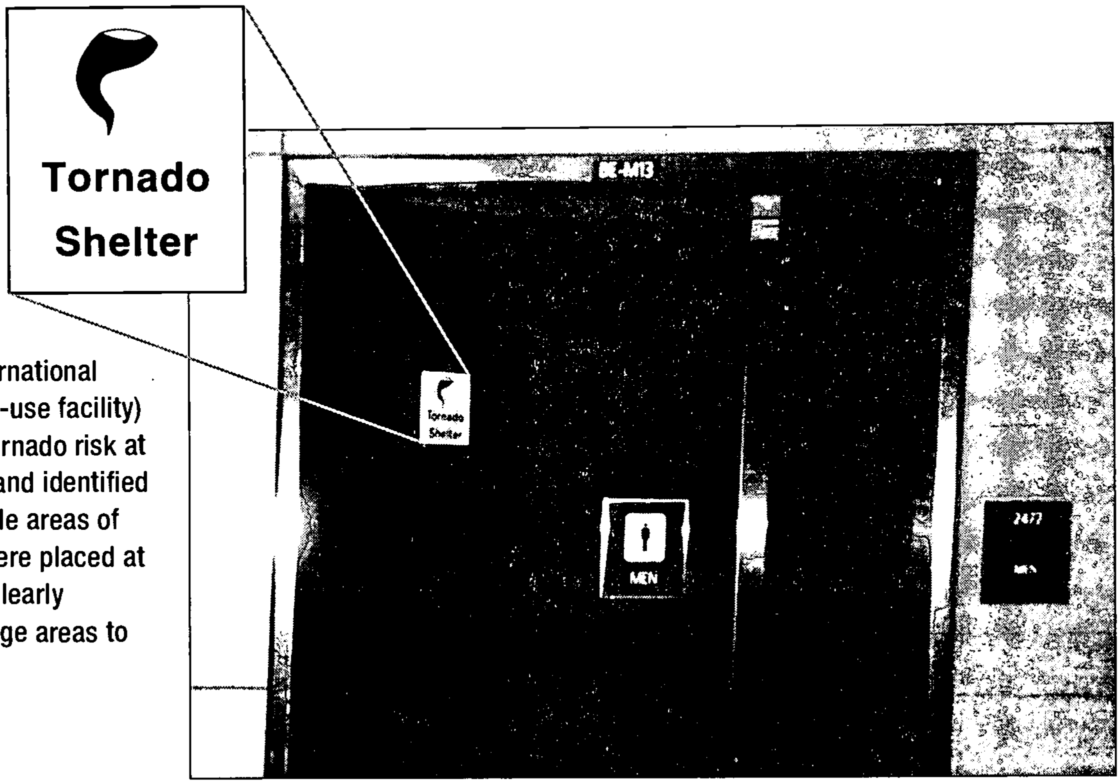


Figure 4-1
The Denver International Airport (a public-use facility) evaluated the tornado risk at the airport site and identified the best available areas of refuge. Signs were placed at these areas to clearly identify the refuge areas to the public.

4.3 Modifying and Retrofitting Existing Space

If a tornado or hurricane shelter is designed and constructed to the criteria presented in this manual, the shelter will provide its occupants with near-absolute protection during a high-wind event.

4.3.1 General Retrofitting Issues

Although retrofitting existing buildings to include a shelter can be expensive and disruptive to users of the space being retrofitted, it may be the only option available. When retrofitting existing space within a building is considered, corridors are often designated as the safest areas because of their short roof spans and the obstruction-free area they provide. Recent shelter evaluation projects have indicated that, although hallways may provide the best refuge in an existing building, retrofitting hallways to provide a near-absolute level of protection may be extremely difficult. Hallways usually have a large number of doors that will need to be upgraded or replaced before near-absolute protection can be achieved based on the criteria outlined in Chapters 5 and 6. Designers should be aware that an area of a building currently used for refuge may not necessarily be the best candidate for retrofitting when the goal is to provide near-absolute protection.

CROSS-REFERENCE

The checklists in Appendix B may be used to identify refuge areas as candidates for retrofit projects.

Examples of interior spaces within buildings where people can take refuge from tornadoes and hurricanes were listed in Section 4.2.2; additional examples include, interior offices, workrooms, and lounges. Guidelines for choosing the best available space are provided in Chapter 2. The design modifications that might be required should follow the recommendations of this manual for new construction (see Appendixes E and F for examples of wall sections, doors, and door hardware that are capable of withstanding the impact of the 100-mph, 15-lb design missile).

Upgrades to improve levels of protection (until a shelter can be designed and constructed) may include the following retrofits:

- replacing existing doors (and door hardware) with metal door systems described in Chapters 5 and 6
- adding metal door systems to replace glazing that is vulnerable to failure from wind pressures or missile impacts
- adding metal door systems to sections of rooms, hallways, and other spaces, and creating protected refuge areas
- removing all glazing, or retrofitting or replacing glazing with either impact-resistant glazing systems or wall sections that meet impact criteria defined in Chapter 6
- adding alcoves to protect existing doors from the direct impact of windborne debris, as described in Chapter 6

NOTE

An existing area that has been retrofitted to serve as a shelter is unlikely to provide the same level of protection as a shelter designed according to the guidance presented in this manual. Also, the additional cost of providing shelter in a new, multi-purpose room is less than the cost of retrofitting an existing space. However, limited space at the proposed shelter site or other constraints may make retrofitting a practical alternative in some situations.

CROSS-REFERENCE

Design criteria for shelter systems are provided in Chapters 5 and 6. Examples of wall and door systems that have passed missile impact tests are presented in Appendixes E and F, respectively.

4.3.2 Specific Retrofitting Issues

An existing area that has been retrofitted to serve as a shelter is unlikely to provide the same level of protection as a shelter designed according to the guidance presented in this manual. BPAT investigations and FEMA-funded projects have indicated that when existing space is retrofitted for shelter use, issues have arisen that have challenged both designers and shelter operators. These issues arise when attempts are made to improve the level of protection in areas not designed originally for shelter or refuge use. When retrofit projects call for improving levels of protection through retrofitting doors, windows, and other openings to meet the missile impact requirements of Chapter 6, the designer should look carefully at the area being retrofitted. For example, protecting the openings of a refuge area that is structurally unable to withstand wind pressures and impact loads will not be a wise retrofit project.

Issues related to the retrofitting of existing refuge areas (e.g., hallways/corridors, bathrooms, workrooms, laboratory areas, kitchens, and mechanical rooms) that should be considered include the following:

- **The roof system.** Is the roof system over the proposed refuge area structurally independent of the remainder of the building? If not, is it capable of resisting the expected wind and debris loads? Are there openings in the roof system for mechanical equipment or lighting that cannot be protected during a high-wind event? It may not be reasonable to retrofit the rest of the proposed shelter area if the roof system is part of a building that was not designed for high wind load requirements.
- **The wall system.** Can the wall systems be accessed so that they can be retrofitted for resistance to wind pressure and missile impact? It may not be reasonable to retrofit a proposed shelter area to protect openings if the walls systems (loadbearing or non-loadbearing) cannot withstand wind pressures or cannot be retrofitted in a reasonable manner to withstand wind pressures and missile impacts.
- **Openings.** Windows and doors are extremely vulnerable to wind pressures and debris impact. Shutter systems may be used on hurricane shelters but should not be relied upon to provide protection for tornado shelters. There is often only minimal warning time before a tornado; therefore, a shelter design that relies on manually installed shutters is impractical. Automated shutter systems may be considered, but they would require a protected backup power system to ensure that the shutters are closed before an event. Doors should be constructed of impact-resistant materials (e.g., steel doors) and secured with six points of connection (typically three hinges and three latching mechanisms). Door frames should be constructed of at least 16-gauge metal and adequately secured to the walls to prevent the complete failure of the door/frame assemblies.

- **The contents of the refuge area.** What are the contents of the refuge area? For example, bathrooms have been used as refuge areas during tornadoes and hurricanes since they often have a minimal number of openings to protect. However, emergency managers may find it difficult to persuade people to sit on the floor of a bathroom when the sanitary condition of the floor cannot be guaranteed. Also, mechanical rooms that are noisy and may contain hot or dangerous machinery should be avoided as refuge areas when possible. The contents of a proposed shelter area (e.g., permanent tables, cabinets, sinks, large furniture) may occupy what was expected to be available space within the shelter, may make the shelter uncomfortable for its occupants, or may pose a hazard to the occupants. These types of shelter areas should be used only when a better option is not available.

4.4 Community Shelters for Neighborhoods

Community shelters intended to provide protection for the residents of neighborhoods require designers to focus on a number of issues in addition to structural design, including ownership, rules for admission, pets, parking, ensuring user access while preventing unauthorized use, and liability. FEMA post-disaster investigations have revealed issues that need to be addressed in the planning of such community shelters. Many of these issues are addressed in the sample **Shelter Operations Plans** in Chapter 9 and Appendix C for community shelters. The following are additional considerations:

CROSS-REFERENCE

Sample community **Shelter Operations Plans** are presented in Chapter 9 and the case study in Appendix C.

- **Access and Entry.** Confusion has occurred during past tornado events when residents evacuated their homes to go to a community shelter but could not get in. During the Midwest tornadoes of May 3, 1999, residents in a Wichita community went to their assigned shelter only to find it locked. Eventually, the shelter was opened prior to the event, but had there been less warning time for the residents, loss of life could have occurred. The Shelter Operations Plan should clearly state who is to open the shelter and should identify the backup personnel necessary to respond during every possible event.

- **Signage.** Signage is critical for users to be able to readily find and enter the shelter. In addition to directing users to the shelter, signs can also identify the area the shelter is intended to serve. Confusion about who may use the shelter could result in overcrowding in the shelter, or, worse, people being turned away from the shelter. Signs can also inform the residents of the neighborhood served by the shelter about the occupancy limitations during any given event. Examples of tornado shelter signage are presented in Chapter 9 and the North Carolina shelter case study in Appendix C.

- **Warning Signals.** It is extremely important that shelter users know the warning signal that means they should report to the shelter. The owners/ operators of shelters should conduct public information efforts (e.g., mass mailings, meetings, flyer distribution) to ensure that the residents of the neighborhood served by the shelter know the meaning of any warning signals to be used.

- **Parking.** Parking at residential shelters can be a problem. Neighborhood residents, who are expected to walk, may instead drive to the shelter from their homes. Residents returning home from work may drive directly to the shelter. Parking problems can adversely affect access to the shelter, again preventing occupants from getting to the shelter before a tornado or hurricane strikes. The Shelter Operations Plan should clearly discuss parking limitations.
- **Pets.** Many people do not want to leave their pets during a disaster. However, tornado and hurricane shelters are typically not prepared to accommodate pets. The policy regarding pets in a community shelter should be clearly stated in the Shelter Operations Plan and posted to avoid misunderstandings and hostility when residents arrive at the shelter.
- **Maximum Recommended Occupancy.** In determining the maximum recommended number of people who will use the shelter, the design professional should assume that the shelter will be used at the time of day when the maximum number of residents are present. A community may also wish to consider increasing the maximum recommended occupancy to accommodate additional occupants such as visitors to the community who may be looking for shelter during a wind event. The maximum recommended occupancy should be posted within the shelter area.

4.5 Community Shelters at Public Facilities

Community shelters at public facilities also require designers to focus on issues other than structural design requirements for high winds. Some issues that have arisen from post-disaster investigation include:

- **Protecting Additional Areas.** If the shelter is at a special needs facility such as a nursing home or hospital, additional areas within the facility may need to be protected. These include medical and pharmaceutical supply storage areas and intensive/critical care areas with non-ambulatory patients. A shelter should address all the needs of its users.
- **Signage.** Signage is critical for users of public facilities to be able to readily find and enter the shelter. However, signage can be confusing. For example, tornado shelters in schools in the Midwest are often designed for use only by the school population, but aggressive signage on the outside of the school may cause surrounding residents to assume that they may use the shelter as well. This may cause overcrowding in the shelter, or, worse, people being turned away from the shelter. Similar problems may occur at hospitals, where the public may go seeking refuge from a tornado or hurricane. The owners/operators of shelters in public-use facilities such as these should inform all users of the facility about the occupancy limitations

of the shelter during any given event. Examples of tornado shelter signage may be found in Chapter 9 and the North Carolina shelter case study in Appendix C.

- **Warning Signals.** It is extremely important that shelter users know the warning signal that means they should report to the shelter. In schools, work places, and hospitals, storm refuge drills and fire drills should be practiced to ensure that all persons know when to seek refuge in the shelter and when to evacuate the building during a fire.
- **Pets.** Many people do not want to leave their pets during a disaster. This is the same problem as identified for the community shelters in neighborhoods. Hurricane and tornado shelters are typically not prepared to accommodate pets. The policy regarding pets in a neighborhood shelter should be clearly stated in the Shelter Operations Plan and posted to avoid misunderstandings and hostility when residents arrive at the shelter.
- **Off-hours Shelter Expectations.** It is important for shelter owners and operators to clearly indicate to the shelter users when the shelter will be open. For example, at a school, will the shelter be accessible after the regular school day? At places of business, will the shelter be accessible after normal work hours? At hospitals, can employees bring their families to the hospital shelter? These types of questions should be anticipated in the design and operation of a community shelter.

CROSS-REFERENCE

Additional human factors criteria are presented in Chapter 8. In addition, sample community Shelter Operations Plans are presented in Chapter 9 and Appendix C.

4.6 Locating Shelters on Building Sites

The location of a shelter on a building site is an important part of the design process for tornado shelters. The shelter should be located such that all persons designated to take refuge may reach the shelter with minimal travel time. Shelters located at one end of a building or one end of a community, office complex, or school may be difficult for some users at a site to reach in a timely fashion. Routes to the shelter should be easily accessible and well marked.

Shelters should be located outside areas known to be floodprone, including areas within the 500-year floodplain. Shelters in floodprone areas will be susceptible to damage from hydrostatic and hydrodynamic forces associated with rising flood waters. Damage may also be caused by debris floating in the water. Most importantly, flooding of occupied shelters may well result in injuries or deaths. Furthermore, shelters located in floodprone areas but properly elevated above the 500-year flood elevation and the elevations of any floods of record will become isolated if access routes are flooded. As a result, shelter occupants could be injured and no emergency services would be available.

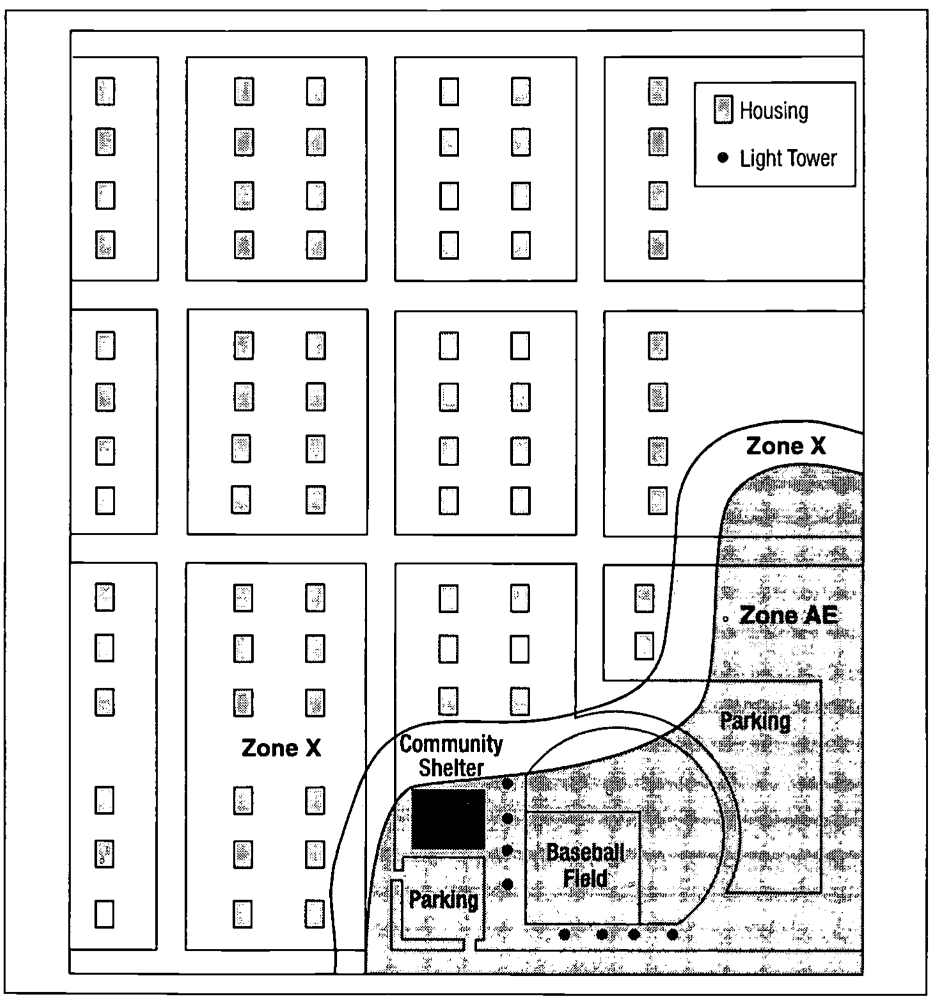
WARNING

Shelters should be located outside known floodprone areas, including the 500-year floodplain, and away from any potential large debris sources.

Where possible, the shelter should be located away from large objects and multi-story buildings. Light towers, antennas, satellite dishes, and roof-mounted mechanical equipment may be toppled or become airborne during tornadoes or hurricanes. Multi-story buildings adjacent to a shelter may be damaged or may fail structurally during tornadoes and hurricanes. When these types of objects or structures fail, they may damage the shelter by collapsing onto it or impacting it. The impact forces associated with these objects are well outside the design parameters of any building code. Some limited debris impact testing was performed in the preparation of this manual and is discussed in Chapter 6.

Examples of improper and proper locations of tornado or hurricane shelters on residential sites are presented in Figures 4-2 and 4-3. Figure 4-2 shows an improperly sited community shelter in a residential area. The shelter is within an SFHA, near large light towers that may fall on the shelter, and near an outside boundary of the community. Figure 4-3 shows a properly sited shelter that is outside the SFHA, away from the towers, and more centrally located within the community.

Figure 4-2
Improperly sited shelter – in an SFHA (Zone AE in this figure), adjacent to light towers that could become falling debris, at the periphery of the community.



NOTE

500-year floodplains are shown as either Zone B or shaded Zone X on FIRMs.

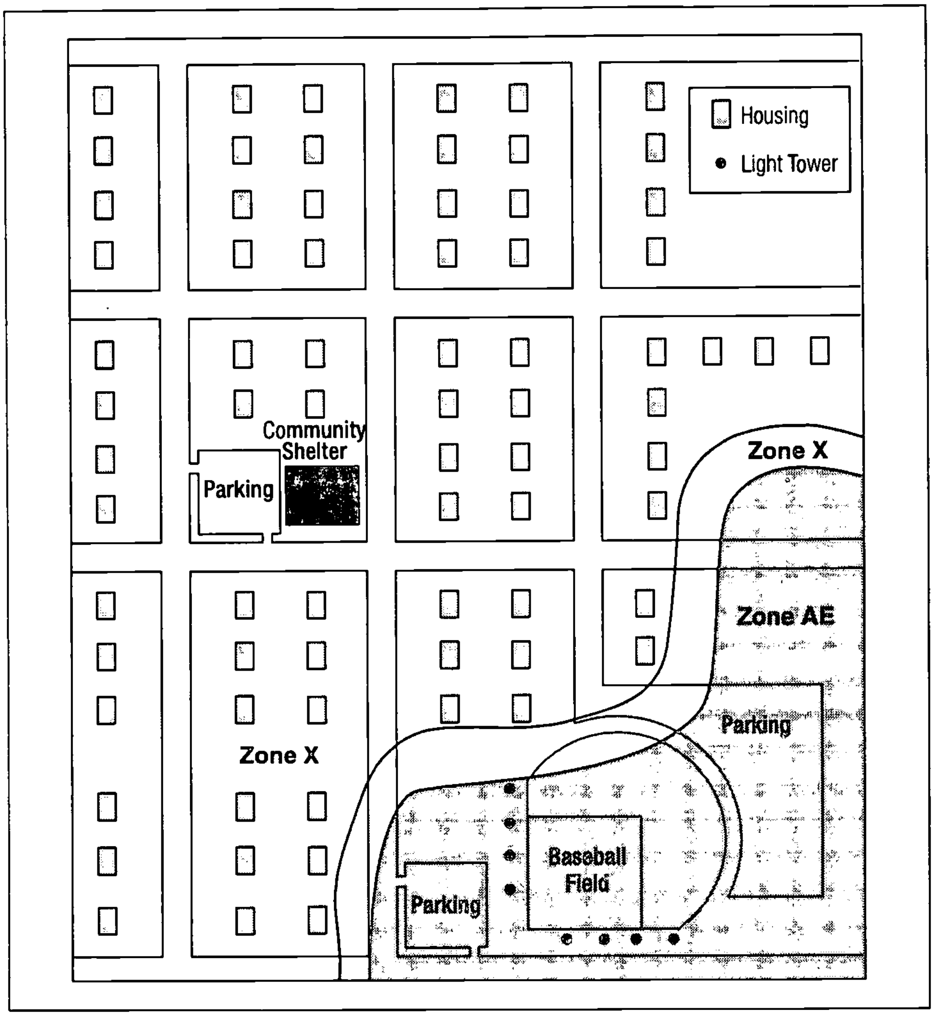


Figure 4-3
Properly sited shelter – outside the SFHA and 500-year floodplain, away from potential falling debris, and centrally located within the community.

NOTE

500-year floodplains are shown as either Zone B or shaded Zone X on FIRMs.

BEST COPY AVAILABLE

5 Load Determination and Structural Design Criteria

This chapter presents a summary of previous research and testing and outlines the recommended methods and criteria for use in the structural design of a community shelter. Other engineering factors and concepts involved in the structural design of a shelter are also discussed in this chapter. Detailed guidance concerning performance criteria for debris impact is presented in Chapter 6. The design criteria presented in this chapter are based on the best information available at the time this manual was published. Commentary intended to provide supplemental guidance to the design professional for this chapter and Chapter 6 is presented in Chapter 10.

5.1 Summary of Previous Guidance, Research, and Testing

To date, the majority of the research, testing, and analysis concerning an interior hardened room has been conducted by the Department of Civil Engineering at Texas Tech University (TTU) and the Department of Civil Engineering at Clemson University (Clemson). At TTU, the Wind Engineering Research Center (WERC) and the Institute for Disaster Research (IDR) managed this work. At Clemson, work was performed at the Wind Load Test Facility (WLTF). Both research universities have performed tests on various combinations of construction materials to determine their resistance to wind-induced forces and the impact of windborne and falling debris.

5.1.1 Previous Design Guidance

Design guidance for high-wind shelters was provided previously in the following FEMA publications and informational documents. (Details about missile tests and testing history are provided in the TTU report *Residential Shelter Design Criteria* in the sections titled "Wind-Generated Missiles" and "Previous Research on Missile Impact." Excerpts from these reports are provided in Appendixes E and F.)

- FEMA 342: *Midwest Tornadoes of May 3, 1999: Observations, Recommendations, and Technical Guidance*
- *National Performance Criteria for Tornado Shelters*
- FEMA 320: *Taking Shelter From The Storm: Building a Safe Room Inside Your House*

CROSS-REFERENCE

See Chapter 10 for descriptions of the FEMA publications listed here.

- FEMA TR-83B: *Tornado Protection: Selecting and Designing Safe Areas in Buildings*
- FEMA TR-83A: *Interim Guidelines for Building Occupant Protection From Tornadoes and Extreme Winds*

5.1.2 Previous Research and Missile Testing

TTU has performed the majority of the previous research and testing on tornado shelters and the effects of tornadoes on buildings. Clemson has conducted tests to determine the effects of hurricanes and lower-intensity tornadoes on buildings. The tests and research performed by these two institutions have included investigating wind speeds and associated loads, wind speed and associated debris impact, and the ability of the building materials to resist these loads and impacts. Tested construction materials (wall sections, doors, door hardware) that meet wind and missile impact criteria of this manual have been summarized and are listed in Appendixes E and F.

The following materials have been successfully tested as part of larger structural systems in laboratory studies developed specifically for shelter designs to resist missile impact:

- 6-inch to 12-inch concrete masonry units (CMU) with at least #4 vertical reinforcing steel, fully grouted in each cell, and horizontal joint reinforcement as required by masonry design code
- reinforced concrete (roof and wall sections at least 6 inches thick) with at least #4 reinforcing steel at 12 inches on center (o.c.) both horizontally and vertically
- 12-gauge steel sheets or heavier
- wood stud cavity walls filled with dry-stacked solid concrete block and encapsulated with plywood sheathing
- 3/4-inch plywood wall panels (when used as exterior cladding in combination with other materials)
- metal doors with at least 14-gauge skin (with interior supports)
- metal doors with less than 14-gauge skin clad with metal sheeting (14 gauge or heavier) attached

Building materials and how they are combined are very important in the design and construction of shelters. If these materials fail, wind may enter the shelter or the shelter itself may fail. Either situation may result in death of or injury to the shelter occupants. The design professional should select materials that will withstand both the design wind loads and the design impact loads.

Many window and door systems have been tested for their ability to resist wind and impact loads associated with high winds. The test protocols usually follow ASTM E 1233/E 330 and ASTM E1886/E 1996, the South Florida Building Code standard, or a similar test standard. Glass products have been produced that may withstand extreme pressures and missile impacts. The designer who wishes to incorporate windows into a shelter should pay close attention on the connections between the glass and the frame, and between the frame and the supporting wall system.

Although the ASTM standard defines how tests are to be performed, and some tests have been performed in hurricane regions of the southeast United States, the impact criteria used for those tests are less than those specified in this manual. Windows and door systems specified for use in extreme-wind shelters should be designed to meet the impact criteria presented in Chapter 6.

WARNING

Tests for doors and windows commonly used in hurricane-prone areas do not meet the criteria for extreme wind pressures and debris impacts recommended in this manual.

5.2 Determining the Loads on the Shelter

The loads that will act on a tornado or hurricane shelter will be a combination of vertical and lateral loads. One methodology of determining these loads is presented in Figure 5-1.

This manual recommends the use of ASCE 7-98 for the calculation of all loads acting on the shelter. Section 5.3 of this manual presents design guidance for calculating the wind pressures and loads associated with the design wind speed selected from Figure 2-2. Using this design wind speed, and the parameters specified in Section 5.3 of this manual for extreme-wind design, the designer should follow the methodology for wind design in Section 6 of ASCE 7-98. Once these loads are determined, the designer should combine all relevant loads acting on the shelter (e.g., dead, live, snow, rain, seismic) and apply them to the shelter. Guidance on load combinations is provided in Section 5.4 of this manual.

NOTE

ASCE 7-98 defines the MWFRS as the main wind force resisting system in a building or structure. Similarly, ASCE 7-98 defines C&C as the components and cladding elements of a building or structure.

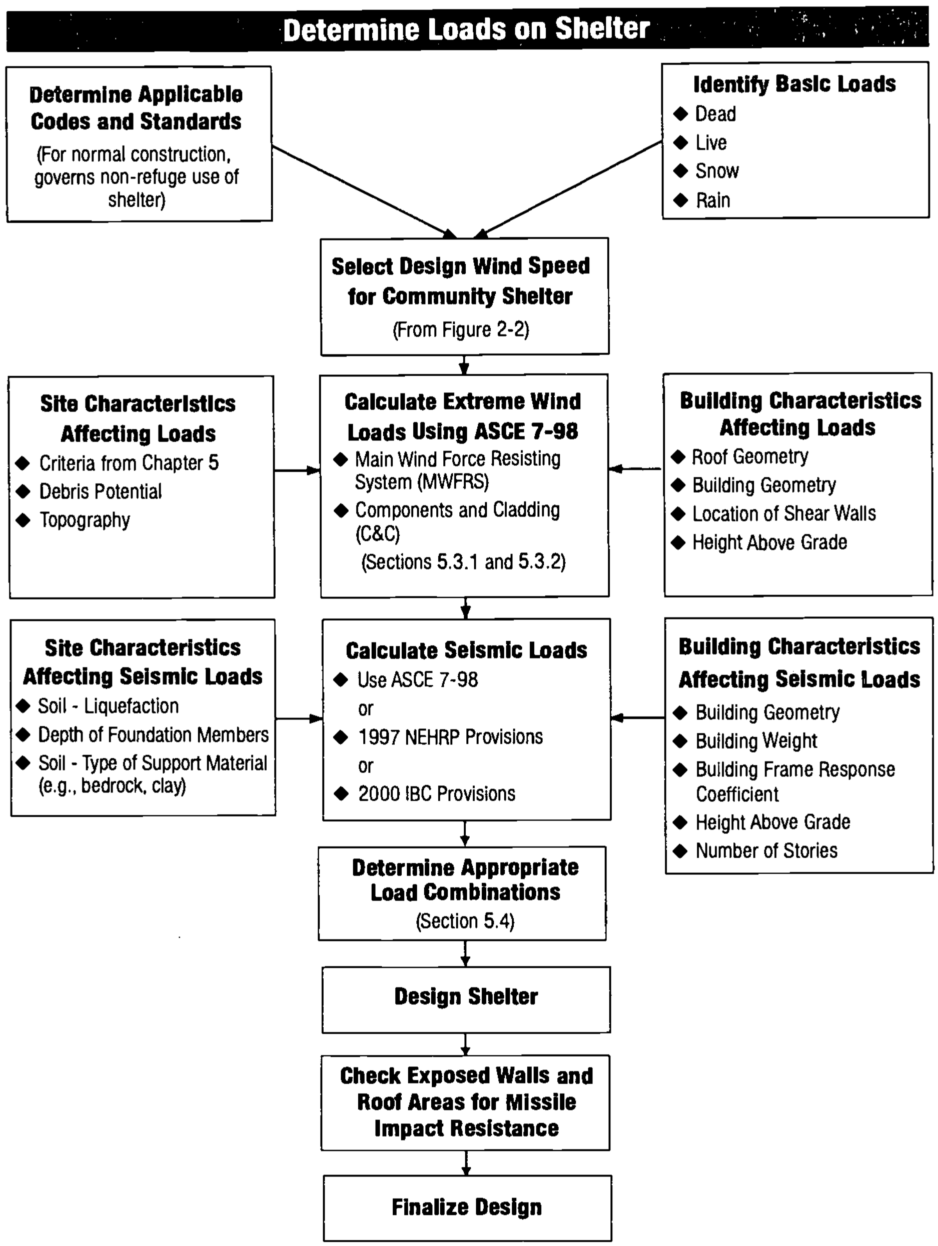
5.3 Determining Extreme-Wind Loads

When wind loads are considered in the design of a building, lateral and uplift loads (discussed in Chapter 3) must be properly applied to the building elements along with all other loads. The design of the shelter relies on the approach taken in ASCE 7-98 for wind loads. For consistency, the designer may wish to use ASCE 7-98 to determine other loads that may act on the shelter. The *International Building Code* (IBC) 2000 and *International Residential Code* (IRC) 2000 also reference ASCE 7-98 for determining wind loads. These wind loads should then be combined with the gravity loads and the code-prescribed loads acting on the shelter in load combinations that are presented in Sections 5.4.1 and 5.4.2 of this manual.

NOTE

C&C elements include wall and roof members (e.g., joists, purlins, studs), windows, doors, fascia, fasteners, siding, soffits, parapets, chimneys, and roof overhangs. C&C elements receive wind loads directly and transfer the loads to other components or to the MWFRS.

Figure 5-1
Shelter design flowchart.



Design wind loads for buildings are generally treated separately for the design of the structural system and the design of the cladding and its attachment to the structural system. Design loads for the structural system of a shelter start with the basic loads from the applicable building code governing the non-refuge use of the shelter. The determination of design wind loads acting on the shelter is based on standard provisions and formulas (equations) for the Main Wind Force Resisting System (MWFRS) as defined in ASCE 7-98. The design of cladding and its attachment to the structural system are based on standard provisions and formulas for the components and cladding (C&C). Wall and roof panels should also be checked for out-of-plane loading associated with C&C loads for the appropriate tributary areas.

5.3.1 Combination of Loads – MWFRS and C&C

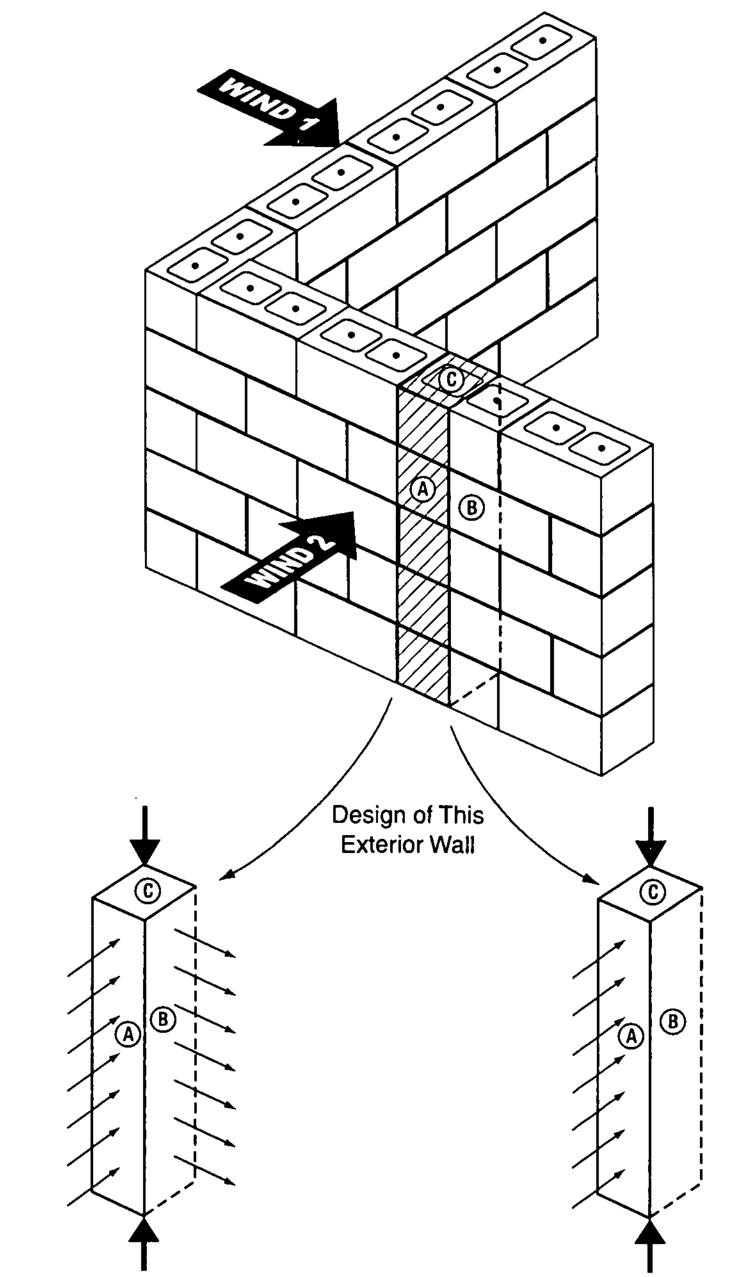
According to ASCE 7-98, the MWFRS is an assemblage of structural elements assigned to provide support and stability for the overall structure and, as a consequence, generally receives wind loading from all surfaces of the building. Elements of the building envelope that do not qualify as part of the MWFRS are identified as C&C and are designed using C&C wind loads. Some elements of low-rise buildings are considered part of the building envelope (C&C) or the MWFRS, depending upon the wind load being considered (e.g., the exterior walls of a masonry building). In the design of these masonry walls, the MWFRS provisions are used to determine the in-plane shear forces, and the C&C provisions are used to determine the out-of-plane design bending load.

The pressure (positive/inward or negative/outward suction) exerted by the wind flowing over and around a building varies with time and location on the building. The highest pressures occur over small areas for a very short time in the regions of a building where the wind flow separation is quite significant. This flow separation can cause small vortices to form that can cause much higher pressures in small localized areas. These flow separation regions generally occur along the edges of the roof and corners of the exterior walls. Therefore, the design wind pressures for the design of the C&C are higher when the tributary area for the element is small and located in a wind flow separation region. The design pressure for a C&C element can be over twice the pressure used to design the structural framing of the building. Proper assessment of the design wind pressures is critical to developing the design of a building's structural frame and the selection of appropriate exterior cladding.

The majority of the wind load provisions are based on wind tunnel modeling of buildings considering non-cyclonic, straight-line winds. Most wind engineers believe that the results from these wind tunnel tests can be used to determine wind pressure from hurricanes. Tornado wind fields are believed to be more complex than the winds modeled in wind tunnel tests that form the basis for the wind loads calculated in ASCE 7-98. However, in investigations of buildings damaged by tornadic winds, the damage is consistent with damage caused by the forces calculated by ASCE 7-98. For this reason, use of ASCE 7-98 provisions provides a reasonable approach to calculating wind loads for tornadoes, even though it is known that these winds are more complex than the wind fields used in the models.

Design wind loads can cause axial, in-plane, and out-of-plane forces to act on the same building element. The combination of these loads should be considered in the design of building walls. For example, consider the exterior reinforced masonry wall shown in Figure 5-2 . Depending on wind direction, the building walls carry different combined loads. For wind direction 1, the wall element shown acts as a shearwall and may experience axial, shear, and

Figure 5-2
MWFRS combined loads and C&C loads acting on a structural member.



Use MWFRS loads when combining loads for wall elements experiencing:

- axial, in-plane (shear), and out-of-plane (bending) loads
- axial and in-plane loads only

Use MWFRS and C&C loads when combining loads for wall elements experiencing axial and out-of-plane loads only. Axial loads are calculated using MWFRS loads; out-of-plane loads are calculated using C&C loads.

bending effects (from wind suction pressures) or axial and shear effects only. When either of these conditions exists, the designer should calculate and combine these loads using MWFRS loads. For wind direction 2, however, the loads on the wall are from axial and out-of-plane bending effects. For this condition, the designer should use MWFRS loads to calculate axial loads and C&C loads to calculate the bending loads when combining loads that affect the design of the wall.

Recommended design wind speeds for geographic regions of the United States are presented in Figure 2-2. Based on the historical and probabilistic data available, the project team believes a shelter can provide near-absolute protection for a specific geographic area (wind zone) if designed for the wind speed specified in the figure. It is important to note that this design approach is a refinement of the approach specified in the 1999 edition of the *National Performance Criteria for Tornado Shelters*, which is to use a design wind speed of 250 mph for all shelter designs throughout the United States.

It has been previously stated that when wind blows over a building, a myriad of forces act on the structure. These forces may cause the building to overturn, deform by racking or bending of components, or collapse and fail at the component junctions or joints. Chapter 3 describes how these wind loads affect a building or shelter. To calculate the loads corresponding to the design wind, the design professional should refer to ASCE 7-98 and Section 5.3.2 when calculating the wind pressures on the shelter.

5.3.2 Assumptions for Wind Calculation Equations Using ASCE 7-98

After the Risk Assessment Plan is completed, the next step in the shelter design process is to select the design wind speed from the map in Figure 2-2. There are four zones on the map that have corresponding wind speeds of 130 mph, 160 mph, 200 mph, and 250 mph. These wind speeds should be used to determine the wind-generated forces that act on either the structural frame or loadbearing elements of a building or shelter (MWFRS) and the exterior coverings of a building or shelter (C&C).

It is recommended that all wind loads, both MWFRS and C&C, be calculated using the wind load provisions in Section 6 of ASCE 7-98. When ASCE 7-98 is used for the design of tornado or hurricane shelters, only *Method 2 – Analytical Procedure* should be used. The design requirements for tornado and hurricane shelters do not meet the requirements for using *Method 1 – Simplified Procedure*. In addition, some of the pressure calculation parameters used in the design of a shelter should be different from those listed in ASCE 7-98 because detailed wind characteristics in tornadoes and hurricanes are not well understood. Based on the wind speed selected from Figure 2-2, the following parameters are recommended for the calculation of wind pressures with *Method 2* of ASCE 7-98:

- Importance Factor (I) — $I = 1.0$
- Site Exposure — C
- Directionality Factor (K_d) — $K_d = 1.0$
- Internal Pressure Coefficient (GC_{pi}) — $GC_{pi} = +/- 0.55$
- Height of the shelter is not restricted

The importance factor (I) is set equal to 1.0. The importance factor for wind loads in ASCE 7-98 is designed to adjust the velocity pressure to different annual probabilities of being exceeded (different mean recurrence intervals [MRIs]). Since the wind speeds in Figure 2-2 are already based on very great MRIs (i.e., low exceedance probabilities), they do not need to be adjusted with the importance factor.

It is recommended that site Exposure C, associated with open terrain, be used to determine design wind forces for shelters. In severe tornadoes and hurricanes, ordinary structures and trees in wooded areas are flattened, exposing shelters to winds coming over open terrain. Also, very little is known about the variation of winds with height in hurricanes and tornadoes. Use of Exposure C is appropriate until the knowledge of localized winds, turbulence characteristics, and boundary layer effects of winds in hurricanes and tornadoes improves.

The directionality factor (K_d) is conservatively set at 1.0. This is done because wind directions may change considerably during a tornado or severe hurricane and a building may be exposed to intense winds from its most vulnerable direction. Therefore, the reduction of this factor allowed in ASCE for normal building design is not recommended for the design of a shelter.

The ASCE 7-98 equations for determining wind loads also include the topographic factor K_{zt}. Damage documentation in hurricane disasters suggests that buildings on escarpments experience higher forces than buildings otherwise situated. No specific observations on topographic effects in tornadic events are available. The designer is advised to avoid siting shelters in locations that are likely to experience topographic effects. If it is necessary to locate a shelter on top of a hill or an escarpment, requirements given in ASCE 7-98 for the topographic factor can be used when calculating wind pressures on shelters that are being designed for hurricane winds only.

The design wind loads/pressures for the MWFRS or the C&C of a building are based on the following factors: velocity pressure, an external gust/pressure coefficient, and an internal gust/pressure coefficient. These coefficients are derived from several factors related to the wind field, the wind/structure interaction, and the building characteristics.

The velocity pressure equation (Equation 6-13, ASCE 7-98) is shown in Formula 5.1. The equation for pressure on a building surface for MWFRS for buildings of all heights (Equation 6-15, ASCE 7-98) is shown in Formula 5.2.

Formula 5.1 Velocity Pressure*

$$q_z = (0.00256)(K_z)(K_{zt})(K_d)(V^2)(I)$$

where: q_z = velocity pressure (psf) calculated at height z above ground
K_z = velocity pressure exposure coefficient at height z above ground
K_{zt} = topographic factor
K_d = directionality factor = 1.0
V = design wind speed (mph) (from Figure 2-2)
I = importance factor = 1.0

*From ASCE 7-98, EQ. 6-13

Formula
Velocity Pressure

Formula 5.2 Pressure on MWFRS for Low-Rise Building*

$$p = (q)(G)(C_p) - (q_i)(GC_{pi})$$

where: p = pressure (psf)
$q = q_z$ for windward walls calculated at height z above ground
$q = q_h$ for roof surfaces and all other walls
G = gust effect factor
C_p = external pressure coefficients
$q_i = q_h$ = velocity pressure calculated at mean roof height
GC_{pi} = internal pressure coefficients = ±0.55

*From ASCE 7-98, EQ. 6-15

Formula
Pressure on MWFRS for Low-Rise Building

The velocity pressure is related to height above ground, exposure, wind directionality, wind speed, and importance factor. Several of these factors account for the boundary layer effects of wind flowing close to the surface of the earth where it interacts with the terrain, buildings, and vegetation.

Values of the exposure factor (K_z) are presented in tabular form in ASCE 7-98. The value of K_z selected should be based on the height of the shelter above grade and the building exposure (Exposure C). The terrain speedup factor (K_{zt}) is based on the acceleration of straight winds over hills, ridges, or escarpments. As previously mentioned, the ASCE provisions for K_{zt} should be followed.

For the MWFRS, the gust effect factor (G) depends on wind turbulence and building dimensions. The gust effect factor can be calculated, or, for a rigid building, G = 0.85 is permitted by ASCE 7-98. The external pressure coefficient (C_p) for the design of the MWFRS is based on the physical dimensions and shape of the building and the surface of the building in relation to a given wind direction.

The equation for pressures on C&C and attachments (Equation 6-18, ASCE 7-98) is shown here in Formula 5.3.

formula

Pressures on C&C and Attachments

Formula 5.3 Pressures on C&C and Attachments*

$$p = (q_h)[(GC_p) - (GC_{pi})]$$

where: p = pressure (psf)
q_h = velocity pressure calculated at mean roof height
GC_p = external pressure coefficients
GC_{pi} = internal pressure coefficients = ±0.55

*From ASCE 7-98, EQ. 6-18

The internal pressure coefficient (GC_{pi}), which incorporates the gust factor (G), accounts for the leakage of air entering or exiting the building where the building envelope has been breached. This leakage creates a pressure increase or a vacuum within the building. The recommended value of GC_{pi} is ±0.55. This value, associated with partially enclosed buildings and applicable to both the MWFRS and C&C components, was selected for the following reasons:

1. In tornadic events, as discussed in Section 3.2.1, maximum wind pressures should be combined with pressure changes induced by atmospheric pressure change (APC) if the building is sealed or, like most shelters, nearly sealed. Although most buildings have enough air leakage in their envelopes that they are not affected by APC, shelters are very "tight" buildings with few doors and typically no windows. If venting is provided in the building envelope to nullify APC-induced pressures, there is a good chance that the building will qualify as a partially enclosed building as defined by ASCE 7-98. However, this venting would require a significant number of openings in the shelter to allow pressures to equalize. Allowing wind to flow through the shelter through large openings to reduce internal pressures (venting) could create an unsatisfactory environment for the occupants, possibly leading to panic among the occupants, injury, or even death. It is important to note that ventilation is needed to ensure that shelter occupants have sufficient airflow to remain safe, but that code-compliant ventilation is not sufficient to nullify APC-induced pressures. Designers who wish to eliminate the need for venting to alleviate APC-induced pressures should

use higher values of GC_{pi} (in shelter design, $GC_{pi} = \pm 0.55$ is recommended). Design pressures determined using wind-induced internal and external pressure coefficients are comparable to the pressures determined using a combination of wind-induced external pressure coefficients and APC-induced pressures. Thus, the resulting design will be able to resist APC-induced pressures, should they occur.

2. In hurricane events, tornadic vortices are often embedded in the overall storm structure. These tornadoes are considered small and less intense than tornadoes occurring in the interior of the country. However, swaths of damage have been noted in several hurricanes. It has not been confirmed whether these swaths are caused by localized gusts or unstable small-scale vortices. As a conservative approach, to design shelters better able to resist long-duration wind forces associated with landfalling hurricanes, designers should use high values of GC_{pi}. This approach will provide reliable and safe designs. It is particularly important that none of the C&C elements (e.g., doors, windows) fail during a windstorm and allow winds to blow through the shelter. The consequences could be the same as those described above for tornadoes.

The value of GC_p for C&C elements is related to the location on the building surface and the effective wind area of the element. For systems with repetitive members, the effective wind area is defined as the span length multiplied by the effective width. When long, slender, repetitive members (e.g., roof joists or rafters) are designed, the effective wind area may be taken as span length multiplied by 1/3 of the span length. It is not uncommon for the effective wind area for a C&C element to be different from the tributary area for the same element (see Figure 5-3). The effective wind area is used to select the coefficient used to calculate the magnitude of the design wind pressure, while the tributary area is the area over which the calculated wind pressure is applied for that specific C&C-designed element.

For cladding fasteners, the effective wind area should not be greater than the area that is tributary to an individual fastener. It should be noted that the external gust/pressure coefficient is constant and maximum for effective wind areas less than 10 ft^2 and constant and minimum for effective wind areas greater than 500 ft^2. If the tributary area of a component element exceeds 700 ft^2, the design wind pressure may be based on the main MWFRS provisions acting on that component.

Once the appropriate MWFRS and C&C wind pressures are calculated for the shelter, they should be applied to the exterior wall and roof surfaces of the shelter to determine design wind loads for the structural and non-structural elements of the shelter. After these wind loads are identified, the designer should assemble the relevant load combinations for the shelter.

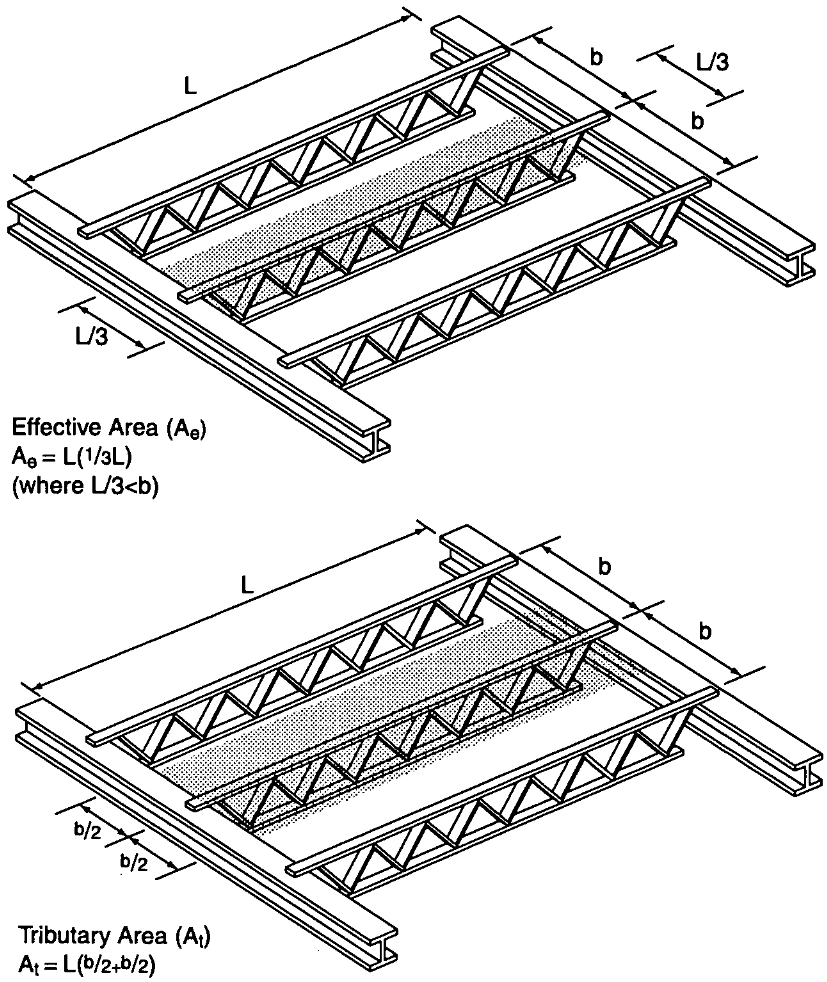


Figure 5-3
Comparison of tributary and effective wind areas for a roof supported by open-web steel joists.

Finally, the designer should not reduce the calculated wind pressures or assume a lower potential for missile impacts on the exterior walls and roof surfaces of an internal shelter. Although a shelter inside a larger building, or otherwise shielded from the wind, is less likely to experience the full wind pressures and missile impacts, it should still be designed for the design wind pressures and potential missile impacts that would apply to a stand-alone shelter. There is no conclusive research that can quantify allowable reductions in design wind pressure for shelters within buildings or otherwise shielded from wind.

5.4 Load Combinations

Model building codes and engineering standards are the best available guidance for identifying the basic load combinations that should be used to design buildings. The design professional should determine the loads acting on the shelter area using the load combinations and conditions for normal building use as defined in the building code in effect or as presented in Section 2 of ASCE 7-98.

The designer should then calculate the extreme wind loads that will act on the shelter using the formulas from this chapter and from Section 6 of ASCE 7-98, for the extreme wind load (W_x). However, it is important to remember that the design wind speed selected from this guidance manual is for an extreme wind; therefore, extreme wind load combinations are provided in Sections 5.4.1 and 5.4.2. These load combinations are based on the guidance given in the *Commentary* of ASCE 7-98 for extreme wind events, are different from those used in either the model codes or ASCE 7-98 (Section 2), and should be used in addition to the basic load combinations.

The load combinations presented in Sections 5.4.1 and 5.4.2 of this manual have been peer reviewed by the Project Team and the Review Committee, but have not been extensively studied. Finally, the design of the shelter may be performed using either Strength Design (Load and Resistance Factor Design [LRFD]) or Allowable Stress Design methods (ASD).

5.4.1 Load Combinations Using Strength Design

The building code in effect should indicate the load combinations to be considered for the design of a building. In the absence of a building code, the designer should use the load combinations of Section 2.3.2 of ASCE 7-98 to ensure that a complete set of load cases is considered. For the MWFRS, C&C, and foundations of high-wind shelters, designers should also consider the following load cases (using W_x) so that the design strength equals or exceeds the effects of the factored loads in the following combinations (LRFD):

Load Combination 1: $1.2D + 1.0W_x + 0.5L$

Load Combination 2: $0.9D + 1.0W_x + 0.5L$

Load Combination 3: $0.9D + 1.2W_x$

where D = dead load, L = live load, and W_x = extreme wind load based on wind speed selected from Figure 2-2.

Wind loads determined from the wind speeds in Figure 2-2 are considered extreme loads. The wind speeds in Figure 2-2 have a relatively low probability of being exceeded, as noted in Section 10.2.4. For this reason, the load factor associated with these wind speeds is considered the same as for an

NOTE

When a shelter is located in a flood zone, the following load combinations in Section 5.4.1 should be considered:

- In V zones and coastal A zones, the $1.0W_x$ in combinations (1) and (2) should be replaced by $1.0W_x + 2.0F_a$.
- In non-coastal A zones, the $1.0W_x$ in combinations (1) and (2) should be replaced by $1.0W_x + 1.0F_a$.

extraordinary event, as suggested in the *Commentary* of ASCE 7-98. Since the extraordinary event is the source of the wind-induced load, a factored load of $1.0W_x$ is used when it is combined with another transient load such as live load, and a factored load of $1.2W_x$ is used when it is the only transient load assumed to act on the building. Dead load factors are 0.9 and 1.2, depending on whether the dead load counteracts the wind loads or adds to them. The load combinations shown above take into account both of these dead load actions.

Finally, the designer should consider the appropriate seismic load combinations in Section 2.3.2 of ASCE 7-98. Where appropriate, the most unfavorable effects from both wind and seismic loads should be investigated. Wind and seismic loads should not be considered to act simultaneously (refer to Section 9.2.2 of ASCE 7-98 for the specific definition of earthquake load, E). From the load cases of Section 2.3.2 of ASCE 7-98 and the load cases listed above, the combination that produces the most unfavorable effect in the building, shelter, building component, or foundation should be used.

NOTE

When a shelter is located in a flood zone, the following load combinations in Section 5.4.2 should be considered:

- **In V zones and coastal A zones, $1.5F_a$ should be added to load combinations (1) and (2).**
- **In non-coastal A zones, $0.75F_a$ should be added to load combinations (1) and (2).**

5.4.2 Load Combinations Using Allowable Stress Design

The building code in effect should indicate the load combinations to be considered for the design of a building. In the absence of a building code, the designer should use the load combinations of Section 2.4.1 of ASCE 7-98, to ensure that a complete set of load cases is considered. For the MWFRS, C&C, and foundations of high-wind shelters, designers should also consider the following load cases (using W_x) so that the design strength equals or exceeds the effects of the factored loads in the following combinations (ASD):

Load Combination 1: $D + W_x + 0.5L$

Load Combination 2: $0.6D + W_x$

where D = dead load, L = live load, and W_x = extreme wind load based on wind speed selected from Figure 2-2.

As mentioned in Section 5.4.1, wind loads determined from the wind speeds in Figure 2-2 are considered extreme loads. At the same time, a shelter is required to protect its occupants during an extreme windstorm. When live load (transient load) is to be combined with wind load, live load is multiplied by a factor of 0.5; no reduction should be taken for wind loads under any circumstances. In addition, allowable stress should not be increased for designs based on the wind loads specified in this document.

Finally, the designer should consider the appropriate seismic load combinations in Section 2.4.1 of ASCE 7-98. Where appropriate, the most unfavorable effects from both wind and seismic loads should be investigated. Wind and seismic loads should not be considered to act simultaneously (refer to Section 9.2.2 of ASCE 7-98 for the specific definition of earthquake load, E.). From the load cases of Section 2.4.1 of ASCE 7-98 and the load cases listed above, the combination that produces the most unfavorable effect in the building, shelter, building component, or foundation should be used.

5.4.3 Other Load Combination Considerations

Concrete and masonry design guidance is provided by the American Concrete Institute International (ACI) and The Masonry Society. *Building Code Requirements for Structural Concrete* (ACI 318-99) and *Building Code Requirements for Masonry Structures* and *Specification for Masonry Structures* (ACI 530-99/ASCE 5-99/TMS 402-99, and ACI 530.1-99/ASCE 6-99/TMS 602-99) are the most recent versions of the concrete and masonry design codes. The load combinations for these codes may differ from the load combinations in ASCE 7-98, the IBC, and other model building codes.

When designing a shelter using concrete or masonry, the designer should use load combinations specified in the concrete or masonry codes, except when the design wind speed is taken from Figure 2-2 in this manual. For the shelter design wind speed, the extreme wind load (W_x) should be determined from the wind pressures acting on the building, calculated according to ASCE 7-98 and the provisions and assumptions stated in Section 5.3 of this manual.

The extreme nature of the design wind speed and the low probability of occurrence was considered by the Project Team in its review of the load combinations for the model codes, ASCE 7-98, and the concrete and masonry codes. When this extreme-wind load is used in combination with dead and live loads, the load combinations provided in Section 5.4.1 or 5.4.2 of this manual should be used. Based on these considerations, no reduction of loads or increases in allowable stresses are recommended.

5.5 Continuous Load Path

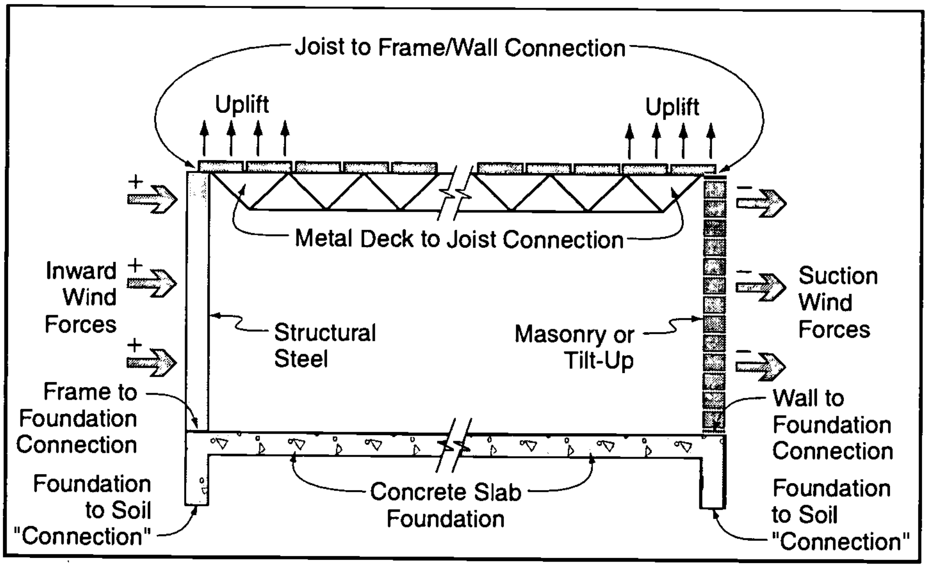
Structural systems that provide a continuous load path are those that support all loads acting on a building: laterally and vertically (inward and outward, upward and downward). Many buildings have structural systems capable of providing a continuous load path for gravity (downward) loads, but they are unable to provide a continuous load path for the lateral and uplift forces generated by tornadic and hurricane winds.

A continuous load path can be thought of as a "chain" running through a building. The "links" of the chain are structural members, connections between members, and any fasteners used in the connections (e.g., nails, screws, bolts, welds, or reinforcing steel). To be effective, each "link" in the continuous load path must be strong enough to transfer loads without permanently deforming or breaking. Because all applied loads (e.g., gravity, dead, live, uplift, lateral) must be transferred into the ground, the load path must continue unbroken from the uppermost building element through the foundation and into the ground.

In general, the continuous load path that carries wind forces acting on a building's exterior starts with the non-loadbearing walls, roof covering and decks, and windows or doors. These items are classified as C&C in ASCE 7-98. Roof loads transfer to the supporting roof deck or sheathing and then to the roof structure made up of rafters, joists, beams, trusses, and girders. The structural members and elements of the roof must be adequately connected to each other and to the walls or columns that support them. The walls and columns must be continuous and connected properly to the foundation, which, in turn, must be capable of transferring the loads to the ground.

Figure 5-4 illustrates typical connections important to continuous load paths in masonry, concrete, or metal frame buildings (e.g., residential multi-family or non-residential buildings); Figure 5-5 illustrates a continuous load path in a typical commercial building. Figure 5-4 also illustrates the lateral and uplift wind forces that act on the structural members and connections. A deficiency in any of the connections depicted in these figures may lead to structural damage or collapse.

Figure 5-4
Critical connections important for providing a continuous load path in a typical masonry, concrete, or metal-frame building wall. (For clarity, concrete roof deck is not shown.)



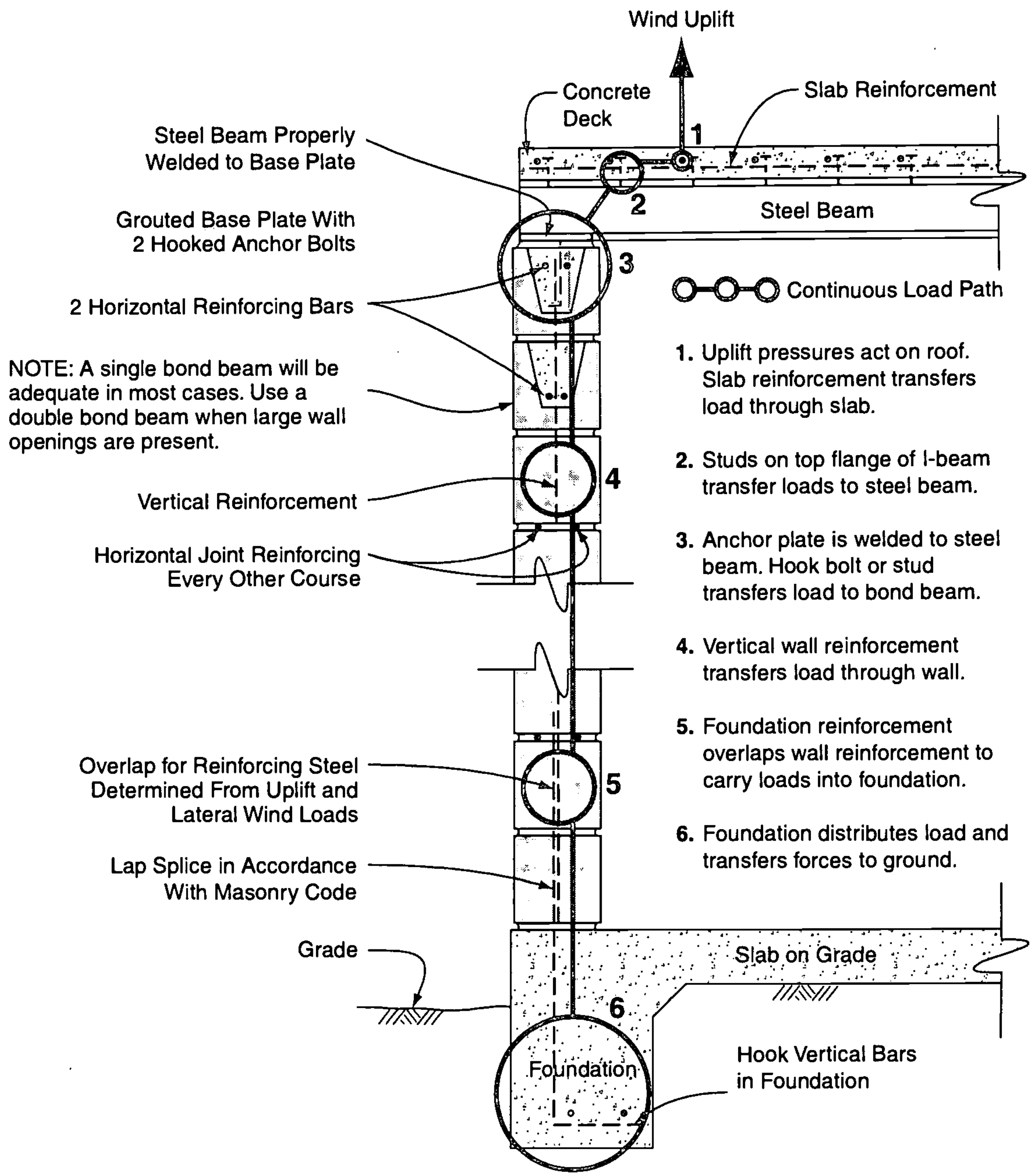


Figure 5-5 Continuous load path in a reinforced masonry building with a concrete roof deck.

In a tornado or hurricane shelter, this continuous load path is essential and must be present for the shelter to resist wind forces. The designers of shelters must be careful to ensure that all connections within the load path have been checked for adequate capacity. Again, designers should refer to ASCE 7-98 and the design wind speed and parameters specified in this manual when determining the loads on the building elements and ensure that the proper pressures are being used for either MWFRS or C&C building elements.

5.6 Anchorages and Connections

A common failure of buildings during high-wind events is the failure of connections between building elements. This failure is often initiated by a breach in the building envelope, such as broken doors and windows or partial roof failure, which allows internal pressures within the building to rapidly increase. This phenomenon is discussed in Chapter 3; the schematic in Figure 3-2 illustrates the forces acting on buildings when a breach occurs.

Anchorage and connection failures can lead to the failure of the entire shelter and loss of life. Therefore, the design of all anchorages and connections should be based on the C&C loads calculated from ASCE 7-98 and on the specified design assumption stated in Section 5.3.2 of this manual. All effects of shear and bending loads at the connections should be considered.

5.6.1 Roof Connections and Roof-to-Wall Connections

Adequate connections must be provided between the roof sheathing and roof structural support, steel joists, and other structural roofing members and walls or structural columns. These are the connections at the top of the continuous load path and are required to keep the roof system attached to the shelter.

Reinforcing steel, bolts, steel studs, welds, screws, and nails are used to connect roof decking to supporting members. The size and number of these connections required for a shelter depend on the wind pressures that act on the roof systems. Examples of connection details that have been designed for some of these conditions may be found in Appendixes C and D for cast-in-place and pre-cast concrete shelter designs.

Figure 5-6 shows damage to a school in Oklahoma that was struck by a tornado. The school used a combination of construction types: steel frame with masonry infill walls and load bearing unreinforced masonry walls. Both structural systems support open-web steel joists with a lightweight roof system composed of light steel decking, insulation, and a built-up roof covering with aggregate ballast.

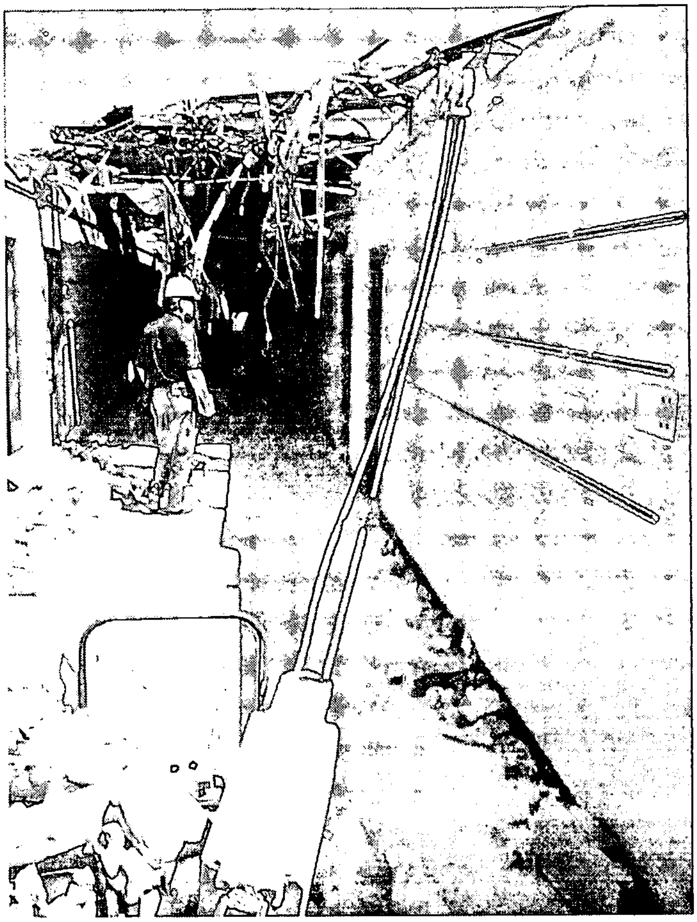


Figure 5-6
Failure in this load path occurred between the bond beam and the top of the unreinforced masonry wall. This school building was in the path of an F4 tornado vortex.

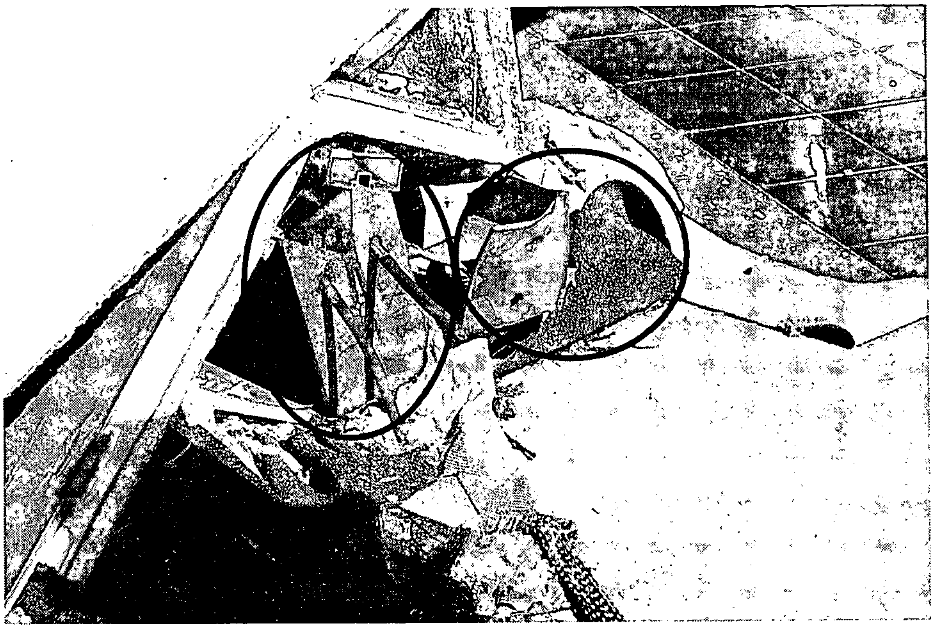
The figure highlights a connection failure between a bond beam and its supporting unreinforced masonry wall as well as the separation of the bond beam from roof bar joists. See Figure 5-5 for an illustration of connections in a reinforced masonry wall that are likely to resist wind forces from a tornado or hurricane. Note that four connection points—between the roof decking and joists, the joist and the bond beam, the bond beam and the wall, and the wall to the foundation—are critical to a sound continuous load path.

5.6.2 Foundation-to-Wall Connections and Connections Within Wall Systems

Anchor bolts, reinforcing steel, and imbedded plate systems properly welded together, and nailed mechanical fasteners for wood construction, are typical connection methods used to establish a load path from foundation systems into wall systems. These connections are the last connections in the load path that bring the forces acting on the building into the foundation and, ultimately, into the ground. The designer should check the ability of the connector to withstand the design forces and the material into which the connector is anchored.

Figure 5-7 shows two columns from a building that collapsed when it was struck by the vortex of a weak tornado. Numerous failures at the connection between the columns and the foundation were observed. Anchor bolt failures were observed to be both ductile material failures and, when ductile failure did not occur, embedment failures.

Figure 5-7
These two steel columns failed at their connection to the foundation. The anchor bolts that secured the column released from the concrete (embedment failure) while the anchor bolts that secured the column on the right experienced a ductile failure.



6 Performance Criteria for Debris Impact

Performance criteria for tornado and hurricane shelters will build on the design criteria in Chapter 5, the existing guidance for residential shelters, and the manuals and publications listed in Section 5.1.1. The most recent of these documents are the *National Performance Criteria for Tornado Shelters* (July 2000), ASCE 7-98, and FEMA 320. Although these documents do not address some factors and elements of the design of extreme-wind shelters, they provide the basis for the criteria presented in this chapter.

Chapter 5 of this manual and ASCE 7-98 present the information necessary for the computation of wind pressures and the loads imposed by winds on the walls, roof, windows, and doors of a shelter area. The walls, ceiling, floor, foundation, and all connections joining these elements will be designed to resist the pressures and loads calculated from the design wind speed without localized element failure and without separating from one another.

The entire shelter structure must resist failure from wind pressures and debris impacts. For the in-residence shelter designs presented in FEMA 320, ceiling spans and wall lengths were no greater than 8 feet and the design of the wall and ceiling was governed by the criteria specified for resistance to the impacts of windborne debris. For larger, community shelters, this broad statement cannot be made; the structural elements and the building envelope must be designed to resist wind-induced loads as well as impacts from debris.

6.1 Missile Loads and Successful Test Criteria

Although there is a substantial body of knowledge on penetration and perforation of small, high-speed projectiles, relatively little testing has been done on lower-speed missiles such as windborne debris impacting buildings. In the design of community shelters or other large shelters, wind loads are likely to control the structural design. However, C&C and building envelope issues may be governed by missile impact requirements. Nonetheless, after the shelter has been designed to withstand wind forces from the design wind speed, the proposed wall and roof sections must be tested for impact resistance from missiles. Roof and wall sections that have been tested for impact from the design missile are presented in Appendix E. A wall or roof section that is the same as the wall sections in Appendix E may be used without additional testing.

6.1.1 Propelled Windborne Debris – Missiles

The standard missile used for the impact tests discussed in FEMA 320 and those specified in FEMA's July 2000 edition of the *National Performance Criteria for Tornado Shelters* has remained unchanged. Although windstorms with wind speeds less than 250 mph typically result in lower missile speeds (for the same size missile), it is recommended that shelter designs be prepared for the missile size and wind speeds indicated in this section.

The standard missile used to determine impact resistance for all wind conditions is defined as follows (based on a representative missile for a 250-mph windstorm):

- 15-lb wood 2x4 (nominal) member
- typically 12 feet long

The missile is assumed to be propelled into wall and roof sections at the following missile speeds and to impact the test specimen (or shelter) 90° to the surface (see Figures 6-1 and 6-2 for examples of damage caused by this missile):

- 100-mph missile speed for horizontally travelling missiles
- 67-mph missile speed for vertically travelling missiles

The static force equivalent of this dynamic impact is difficult to calculate, and a direct conversion to a static load often results in extremely large loads. The actual impact force of the missile varies with the material used for the wall or roof section and will be a function of the stiffness of the material itself as well as the overall stiffness of the wall section in which it is used. Therefore, no formula for the determination of impact load is provided in this manual.

Various wall and roof sections tested at the WERC at TTU performed successfully. They are summarized in Chapter 6 and described in detail in Appendix E. The designer is referred to Appendix G for a selection of wall materials that have successfully passed missile impacts under the criteria outlined above.

6.1.2 Falling Debris

Falling debris also create structural damage, the magnitude of which is a function of the debris size and distance the debris falls. Falling debris generally consists of building materials and equipment that have significant mass and fall short distances from taller structures nearby. When siting the shelter, the designer should consider placing the shelter away from a taller building or structure so that if that structure collapses, it will not directly impact the shelter. When this cannot be done, the next best alternative would

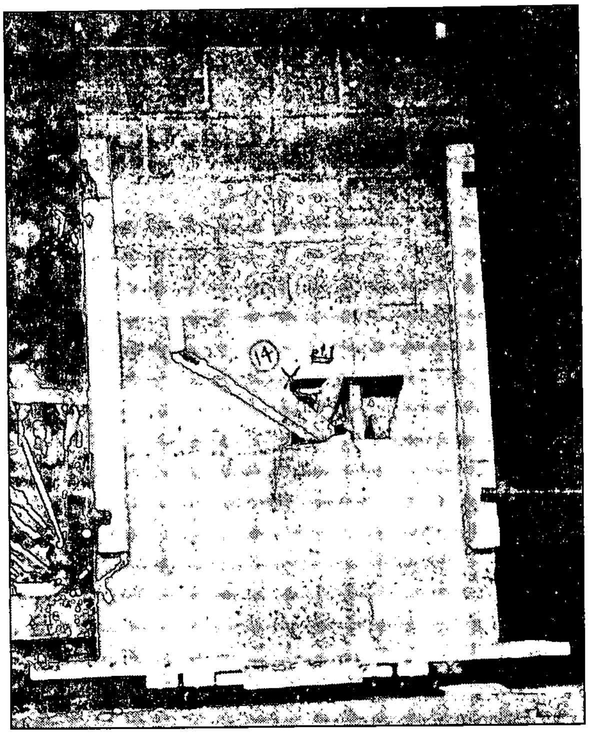


Figure 6-1
Wood 2x4 launched at 100 mph pierced unreinforced masonry wall, WERC, Texas Tech University.

Figure 6-2
Refrigerator pierced by windborne missile.

be to site the shelter in such a way that no large structure is within a zone around the shelter defined by a plane that is 1:1 (vertical to horizontal) for the first 200 feet from the edge of the shelter.

If it is not possible to site the shelter away from all the falling debris hazards at a site, the designer should consider strengthening the roof and wall systems of the shelter for the potential dynamic load that may result from these large objects impacting the shelter. Minimal guidance concerning the dynamic effect of large pieces of debris impacting shelters is available; however, the results of some limited testing, and approaches for designing for these loads, are discussed later in this chapter as performance criteria.

6.2 Windborne Debris (Missile) Impacts

The quantity, size, and force of windborne debris (missiles) generated by tornadoes and large hurricanes are unequaled by those of other windstorm debris. Missiles are a danger to buildings because the debris can damage the structural elements themselves or breach the building envelope. If the missile breaches the building envelope, wind may enter the building, resulting in an overpressurization of the building that often leads to structural failures. This high potential for missiles capable of breaching a building's exterior supports the recommended use of the internal pressure coefficient for partially enclosed buildings in the design criteria presented in Section 5.3. In addition, windborne debris may kill or injure people who cannot find shelter or refuge during a tornado or hurricane.

Most experts group missiles and debris into three classifications. Table 6.1 lists the classifications, presents examples of debris, and describes expected damage.

Table 6.1
Windborne Debris (Missiles) and Debris Classifications for Tornadoes and Hurricanes

MISSILE SIZE	TYPICAL DEBRIS	ASSOCIATED DAMAGE OBSERVED
Small (Light Weight)	Aggregate roof surfacing, pieces of trees, pieces of wood framing members, bricks	Broken doors, windows, and other glazing; some light roof covering damage
Medium (Medium Weight)	Appliances, HVAC units, long wood framing members, steel decking, trash containers, furniture	Considerable damage to walls, roof coverings, and roof structures
Large (Heavy Weight)	Structural columns, beams, joists, roof trusses, large tanks, automobiles, trees	Damage to wall and roof framing members and structural systems

Although large pieces of debris are sometimes found in the aftermath of extreme wind events, heavy pieces of debris are not likely to become airborne and be carried at high speeds. Therefore, from research in the field after tornadoes and hurricanes, as well as the results of research at TTU studying windborne debris in various wind fields, the representative missile has been selected as a 15-lb wood 2x4 (12–14 feet long).

This is the same missile criterion specified in Chapter 5 of this manual. Wind events have been modeled to show that the selected 15-lb missile will have different speeds and trajectories, depending on the event. However, to be conservative, it is recommended that test criteria for missile impact resistance be as stated in this section and Section 6.1.1.

Comparisons of results from missile impact tests for missiles other than the 15-lb wood 2x4 traveling at the design missile speed are discussed in Appendix G.

6.2.1 Debris Potential at Shelter Sites

Debris impacting buildings during a severe windstorm can originate from both the surrounding area and from the building itself and is not limited to the representative missile discussed in Section 6.2. During the development of a shelter design, the design professional should review the site to assess potential missiles and other debris sources in the area.

In addition to the wood 2x4 member described in the previous section, roof coverings are a very common source of windborne debris (missiles) or falling debris (ranging from roof gravel or shingles to heavy clay tiles, slate roof coverings, and roof pavers). Other sources of debris include roof sheathing materials, wall coverings, roof-mounted mechanical equipment, parapets, garbage cans, lawn furniture, missiles originating from trees and vegetation in the area, and small accessory buildings. Missiles originating from loose pavement and road gravel have also been observed in intense windstorms. In one area impacted by Hurricane Andrew, mailboxes were filled with rocks and asphalt from surrounding roadways.

As buildings break apart in severe windstorms, the failures progress from the exterior building elements inward to the structural members (e.g., trusses, masonry units, beams, and columns). The literature on tornadoes and hurricanes contains numerous examples of large structural members that have been transported by winds for significant distances. Generally, large debris such as structural members are transported significant distances by the windfield when a portion of exterior sheathing remains connected and provides an aerodynamic sail area on which the wind can act.

Rooftop mechanical equipment that is kept in place only by gravity connections is a source of heavy deformable debris when displaced during high-wind events. Furthermore, additional vulnerabilities to missile and wind are created when rooftop equipment is displaced from the roof, leaving large openings in the roof surface. Cars and trucks are also moved by strong winds. Lightweight vehicles can be moved around in parking lots in winds with gust speeds approaching 100 mph. Although pieces of debris larger than the test missile (15-lb 2x4) are observed, the speed of these missiles is considerably less. From post-disaster investigations, the 2x4 test missile appears most representative of the high-energy missile most likely to penetrate conventional construction. However, a shelter that has been designed to provide punching shear resistance from a 15-lb wood 2x4 and the capacity to resist the large wind forces associated with an extreme wind event will likely provide protection for some level of impact from larger debris items. Additional design guidance concerning large falling debris is presented in Section 6.3.

6.2.2 Induced Loads From the Design Missile and Other Debris

Determining static design loads from a propelled missile or a piece of free-falling debris is a complex computation. This computation depends on a number of factors, including the following:

- material that makes up the missile or falling debris
- material of the wall, door, window, or roof section being impacted
- stiffness of the individual elements being impacted
- stiffness of the structural system supporting them
- angle of impact between the missile and the structure

Because of the complex nature of missile and debris impacts, this manual does not provide design criteria that can be used to calculate the static force of a missile impact on any part of the shelter. To determine adequate missile impact resistance for a shelter, the designer should use the performance criteria presented in this chapter and the results of successful wall, roof, door, and window tests that are presented in Appendixes E and F of this manual.

6.2.3 Impact Resistance of Wood Systems

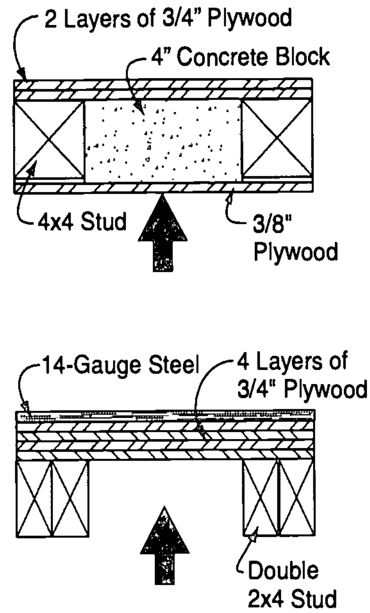
Texas Tech University has conducted extensive testing of wall systems that use plywood sheathing. The most effective designs, in terms of limiting the number of layers of plywood required, incorporate masonry infill of the wall cavities or integration of 14-gauge steel panels as the final layer in the system. Appendix E shows wall sections that have been tested with the design missile without failing (i.e., provide adequate missile impact resistance). Examples are shown in Figure 6-3.

a

4x4 stud wall, containing 4-inch concrete block, with one layer of 3/8-inch CD grade plywood on the impact face and two layers of ¾-inch CD grade plywood on the non-impact face

b

Double 2x4 stud wall with 4 layers of ¾-inch CD grade plywood and 14-gauge steel on the back face



The arrow shows the direction of missile impact and indicates the side of the wall that was impacted.

Figure 6-3
Wall sections constructed of plywood and masonry infill (a) and plywood and metal (b).

For conventional light-frame construction, the side of the wall where the sheathing or protective material is attached and the method of attachment can affect the performance of the wall in resisting damage from the impact of windborne debris. The impact of debris on material attached to the outside (i.e., harm side) of a wall pushes the material against the wall studs. Material attached to the inside of the wall (i.e., safe or shelter side) can be knocked loose from the studs if it is not adequately attached to the studs. Similarly, material on the harm side would be susceptible to being pulled off the studs by wind suction pressures if it were not adequately attached to the studs.

Consequently, sheathing materials bearing on the framing members should be securely attached to the framing members. Tests have shown that sheathing attached using an **AFG-01** approved wood adhesive and code-approved #8 screws (**not** drywall screws) penetrating at least 1-1/2 inches into the framing members and spaced not more than 6 inches apart provides sufficient capacity to withstand expected wind loads if the sheathing is attached to the exterior surfaces of the wall studs. These criteria are also sufficient to keep the sheathing attached under impact loads when the sheathing is attached to the interior surfaces of the studs. For information about oriented strand board or particleboard sheathing, see Appendix G.

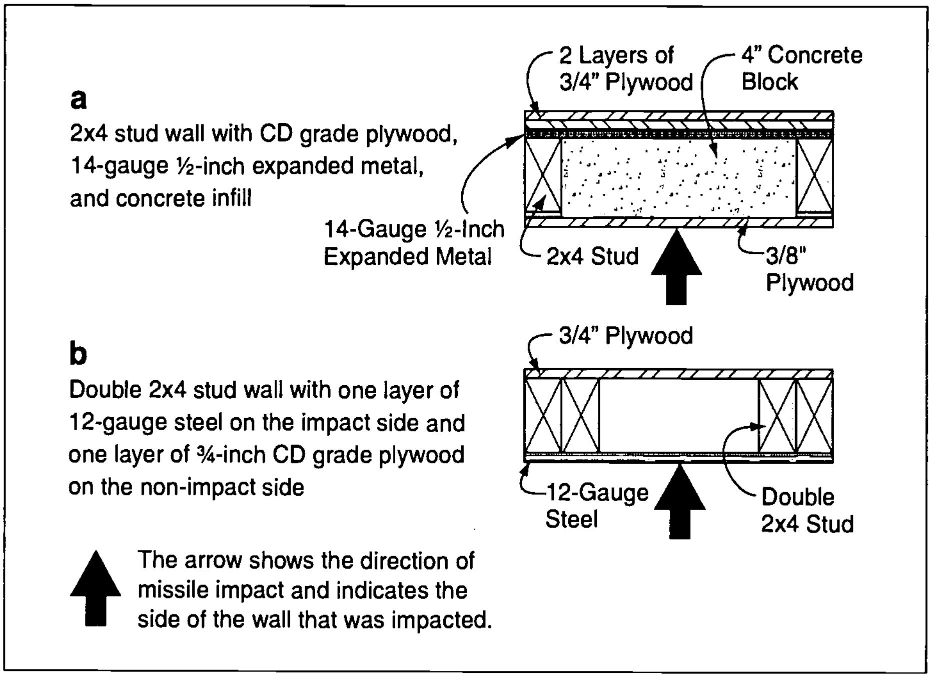
DEFINITION

AFG-01 is an American Plywood Association (APA) specification for adhesives for field gluing plywood to wood framing.

6.2.4 Impact Resistance of Sheet Metal

Various gauges of cold rolled A569 and A570 Grade 33 steel sheets have been tested in different configurations (see Figure 6-4 for an illustration of a representative wall section). The steel sheets stop the missile by deflecting and spreading the impact load to the structure. Testing has shown that if the metal is 14 gauge or lighter and is backed by any substrate that prevents deflection of the steel, the missile will perforate the steel. If the 14-gauge or lighter steel sheets are placed between plywood layers or between plywood and studs, the steel does not have the ability to deflect and is perforated by the missile. Therefore, on a wood stud wall, a 14-gauge steel sheet can resist perforation only when it is used as the last layer on the non-impact face on the interior (shelter side) of the wall, as shown in Figure 6-3.

Figure 6-4
Uses of expanded metal (a) and sheet metal (b) in wall sections.



In laboratory tests at Texas Tech University, 12-gauge or heavier steel sheets have never been perforated with the 15-lb wood 2x4 traveling at 100-mph. The 12-gauge steel has been mounted directly to studs and mounted over solid plywood. Test samples have used the standard stud spacing of 16 inches on center (o.c.). Increased spacing between supports affects the permanent deformation of the steel sheet. Permanent deformation of 3 inches or more after impact is deemed unacceptable. Tests have not been performed to determine the maximum support spacing that would control the 3-inch permanent deformation limit.

Designs provided in FEMA 320 include the use of sheet metal in shelter roof construction. If sheet metal alone is relied on for missile impact protection, it should be 12 gauge or heavier.

6.2.5 Impact Resistance of Composite Wall Systems

Composite wall systems require rigorous testing because there is no adequate method to model the complex interactions of materials during impact. Tests have shown that impacting a panel next to a support can cause perforation while impacting midway between supports results in permanent deformations but not perforation. Seams between materials are the weak links in the tested systems. The location and length of seams between different materials are critical. Currently the best way to determine the missile shielding ability of a composite wall system is to build and test a full-scale panel that consists of all the materials and structural connections to be used in constructing the panel. See Figure 6-5 for an illustration of a representative composite wall section.

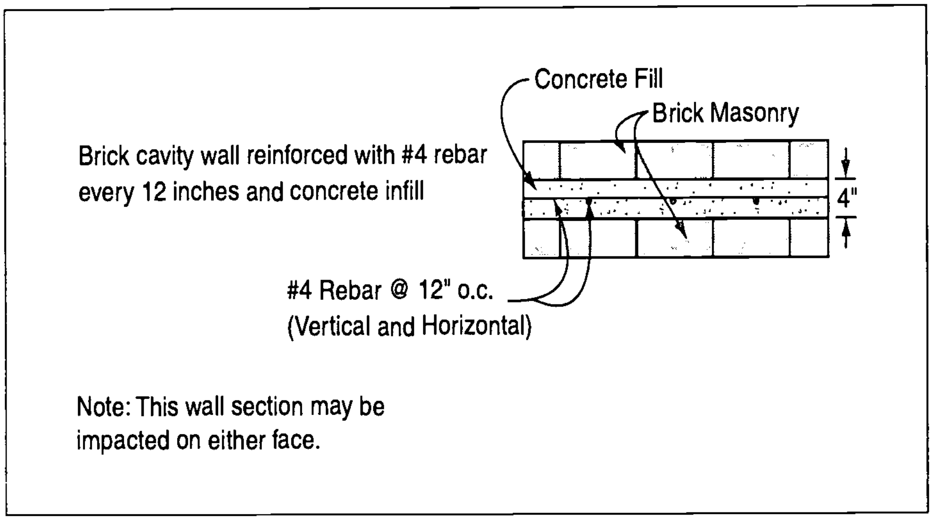


Figure 6-5
Composite wall section.

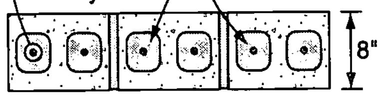
6.2.6 Impact Resistance of Concrete Masonry Units

Texas Tech research has demonstrated that both 6- and 8-inch-thick concrete masonry unit (CMU) walls that are fully grouted with concrete and reinforced with #4 reinforcing steel (rebar) in every cell (see Figure 6-6) can withstand the impact of a 15-lb 2x4 wood member striking perpendicular to the wall with speeds in excess of 100 mph.

Figure 6-6
Concrete masonry unit (CMU) wall sections.

a
6-inch CMU reinforced with concrete and #4 rebar in every cell; each course is staggered

b
8-inch CMU reinforced with concrete and #4 rebar in every cell; each course is staggered



Note: These wall sections may be impacted on either face.

6.2.7 Impact Resistance of Reinforced Concrete

Research related to the design of nuclear power facilities has produced a relatively large body of information and design guides for predicting the response of reinforced concrete walls and roofs to the impact of windborne debris. The failure modes have been identified as penetration, threshold spalling, spalling, barrier perforation, and complete missile perforation (Twisdale and Dunn 1981). From a sheltering standpoint, penetration of the missile into, but not through, the wall surface is of no consequence unless it creates spalling where concrete is ejected from the inside surface of the wall or roof. Spalling occurs when the shock wave produced by the impact creates tensile stresses in the concrete on the interior surface that are large enough to cause a segment of concrete to burst away from the wall surface. Threshold spalling refers to conditions in which spalling is just being initiated and is usually characterized by small fragments of concrete being ejected. When threshold spalling occurs, a person directly behind the impact point might be injured but is not likely to be killed.

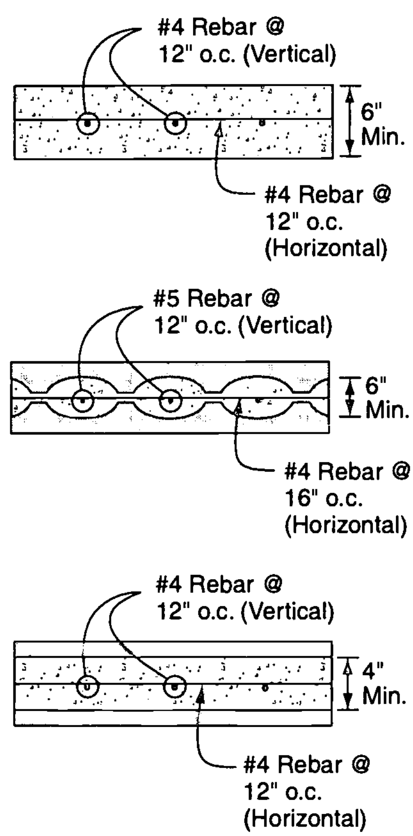
However, as the size of the spalling increases, so does the velocity with which it is ejected from the wall or roof surface. When spalling occurs, injury is likely for people directly behind the impact point and death is a possibility. In barrier perforation, a hole occurs in the wall, but the missile still bounces off the wall or becomes stuck in the hole. A plug of concrete about the size of the missile is knocked into the room and can injure or kill occupants. Complete missile perforation can cause injury or death to people hit by the primary missile or wall fragments. Design for missile impact protection with reinforced concrete barriers should focus on establishing the minimum wall thickness to prevent threshold spalling under the design missile impact. Twisdale and Dunn (1981) provide an overview of some of the design equations developed for nuclear power plant safety analysis.

It should be noted that the missiles used to develop the analytical models for the nuclear industry, which are most nearly suitable for wood structural member missiles, are steel pipes and rods. Consequently, the models are expected to provide conservative estimates of performance when a "softer" missile, such as a wood structural member, impacts the walls. A summary of test results from a number of investigations (Twisdale and Dunn 1981) suggests that 6-inch-thick reinforced concrete barriers are needed to stop a 15-lb wood 2x4 missile impacting at 100 mph without threshold spalling. Texas Tech University research indicates that a 6-inch reinforced concrete wall (see Figure 6-7, illustrations a and b) provides sufficient protection from the 15-lb wood 2x4 missile impacting at 100 mph. Furthermore, reinforced concrete walls constructed with insulating concrete forms with a concrete section 4 inches thick (see Figure 6-7, illustration c) also provide sufficient protection. The Texas Tech University research also shows that a 4-inch-thick reinforced concrete roof provides sufficient protection from a 15-lb wood 2x4 missile impacting at 67 mph (the free-falling missile impact speed recommended in this document).

a
Reinforced concrete wall, at least 6 inches thick, reinforced with #4 rebar every 12 inches both vertically and horizontally)

b
Insulating concrete form (ICF) waffle grid wall section at least 6 inches thick reinforced with #5 rebar every 12 inches vertically and #4 rebar every 16 inches horizontally

c
Insulating concrete form (ICF) flat wall section at least 4 inches thick reinforced with #4 rebar every 12 inches both vertically and horizontally



Note: These wall sections may be impacted on either face.

Figure 6-7
Reinforced concrete wall section (a), reinforced concrete "waffle" wall constructed with insulating concrete forms (b), and reinforced concrete "flat" wall constructed with insulating concrete forms (c).

6.3 Large Falling Debris

The design requirements for the wind speed selected from Figure 2-2 and the representative missile impact criteria outlined in Section 6.2 provide most shelter designs with roof and wall sections capable of withstanding some impacts from slow-moving, large (or heavy) falling debris. The residual capacity that can be provided in shelter designs was the subject of limited large debris impact testing at Clemson University. The purpose of this testing was to provide guidance on the residual capacity of roof systems when the shelter is located where falling debris may be a hazard. In this testing, two types of shelter roofs were subjected to impacts from deformable, semi-deformable, and non-deformable debris released from heights up to 100 feet and allowed to impact the roofs by free-fall.

Non-deformable debris included barrels filled with concrete weighing between 200 and 1,000 lb. Semi-deformable debris included barrels filled with sand weighing between 200 and 600 lb, while deformable debris included heating/ventilation/and air-conditioning (HVAC) components and larger objects weighing from 50 to 2,000 lb. Impact speeds for the falling debris were calculated from the drop height of the debris. The speed of the objects at impact ranged from approximately 17 to 60 mph. Impacts were conducted in the centers of the roof spans and close to the slab supports to observe bending, shear, and overall roof system reactions.

Cast-in-place and pre-cast concrete roof sections were constructed from the design plans in Case Studies I and II in Appendixes C and D, respectively. The heavily reinforced, cast-in-place concrete roof performed quite well during the impact testing. Threshold spalling, light cracking, to no visible damage was observed from impacts by deformable missiles, including the large 2,000-lb deformable object that impacted the slab at approximately 60 mph. Impacts from the 1,000-lb concrete barrel did cause spalling of concrete from the bottom surface of the roof near the center of the slab that would pose a significant hazard to the occupants directly below the point of impact. However, significant spalling required relatively high missile drops (high impact speeds).

Spalling of the slab extended into the slab from the bottom surface to the middle of the slab during impacts from the 1,000-lb concrete barrel impacting at approximately 39 mph. During this heavy spalling, the largest fragments of concrete were retained in the roof by the steel reinforcing. Metal decking (22 gauge) was successfully used as cast-in-place formwork on one of the test samples to retain concrete spalls created by the falling debris. The metal decking, however, must be connected to reinforcing within the slab or secured to the concrete to contain the spalling concrete.

The 1,000-lb concrete barrel completely perforated the flange of the double-tee beam in one drop from 50 feet (impacting at 39 mph) and caused significant damage to the stem in a second drop from the same height. Little damage occurred when the deformable debris materials (HVAC units, the 300-lb sand barrels, and a 1,500-lb deformable object) were dropped on the double-tee beams. Only light cracking and threshold spalling were observed from impacts from these deformable objects.

Based on the observed behavior of these roof specimens, it is believed that roof designs that incorporate a uniform thickness (i.e., flat slab) provide a more uniform level of protection from large debris impacts, anywhere on the roof, than a waffle slab, ribbed slab, or other designs that incorporate a thin slab supported by secondary beams. This approach is the best means of protecting shelter occupants from large impacts on shelter roof systems if siting the shelter away from potential falling debris sources is not a viable solution. Future research may yield information that will result in a more refined approach to designing shelters to resist the forces created by large falling debris.

6.4 Doors and Door Frames

Door failures are typically related to door construction and door hardware. Previous research and testing has determined that steel doors with 14-gauge or heavier skins prevent perforation by the design missile traveling horizontally at 100 mph. Furthermore, such doors in widths up to 3 feet are capable of withstanding wind loads associated with wind speeds up to 250 mph when they are latched with three hinges and three deadbolts. Because community shelters may have doors larger than those previously tested for use in in-home safe rooms, testing was performed for doors up to 44 inches wide. Double-door systems with center mullions and different types of closure hardware were also tested. The information presented here and in Appendix F is a compilation of the test information available to date.

NOTE

The design pressure for a 250-mph wind on doors in wall corner regions of a community shelter is 1.75 psi for components and cladding (C&C) elements with an area of 21 ft². Locating the door outside the corner region reduces the design pressure for the door to approximately 217 psf or 1.5 psi (corner regions are defined as the first 3 feet from the corner, 10 percent of the least wall dimension, or 4 percent of the wall height). These pressures are different from the 1.37-psi maximum door pressure used for the small, flat-roofed shelters in FEMA 320 that were assumed to be designed for "enclosed building" conditions (as defined in ASCE 7-98).

Critical wind loads on doors and door frames are calculated according to the guidance presented in Chapter 5 of this manual and ASCE 7-98 for C&C loading. Calculations indicate that the maximum wind load expected on a door system (due to external suction wind forces combined with internal pressures for a 250-mph design wind) is 250 psf or 1.75 psi. Doors have been tested at these pressures through laboratory pressure tests. The doors were tested with positive pressure. The doors and frames were mounted as swing-in or swing-out doors to simulate either positive or negative pressures acting on the door. The doors were tested from both sides with positive pressure because the door and frame could not be sealed properly to pull a vacuum on the door to simulate negative pressures. Sliding door systems have been tested in the same manner.

NOTE

The weak link of door systems when resisting wind pressures and debris impact is the door hardware. Testing was performed on a limited number of door and door hardware systems that represented off-the-shelf products to indicate their expected performance in shelters. Although these systems passed the missile impact tests, they did not pass the maximum wind pressure tests. The maximum wind pressures on any shelter occur at building corners in Wind Zone IV. Therefore, any shelter door system in Wind Zone IV should be protected by an alcove or debris barrier until further testing can be performed or until other door and hardware systems are successfully tested for the design wind pressures. See Appendix F for more detailed guidance.

6.4.1 Door Construction

Door construction (primarily the exterior skin) has been found to be a limiting element in the ability of a door to withstand missile impacts, regardless of the direction of door swing (inward or outward). Both steel and wood doors have been tested for missile impact resistance. Previous research and testing has determined that steel doors with 14-gauge or heavier skins prevent perforation by the design missile. Furthermore, such doors in widths up to 3 feet are capable of withstanding forces associated with wind speeds up to 250 mph when they are latched with three hinges and three deadbolts. At this time, no wood door, with or without metal sheathing, has successfully passed either the pressure or missile impact tests using the design criteria for 250-mph winds.

6.4.1.1 Single-Door Systems Less Than 36 Inches Wide

The following is a list of single-door systems less than 36 inches wide that have successfully withstood the missile impact criteria of this manual:

- Steel doors with exterior skins of 14 gauge or thicker. These doors can be used without modification of the exterior skin. The internal construction of the doors should consist of continuous 14-gauge steel channels as the hinge and lock rails and 16-gauge channels at the top and bottom. The minimum hardware reinforcement should be 12 gauge. The skin should be welded the full height of the door. The weld spacing on the lock and hinge rails should be a maximum of 5 inches o.c. The skin should be welded to the 16-gauge channel at the top and bottom of the door with a maximum weld spacing of 2-1/2 inches o.c. The door may include fill consisting of polystyrene infill or a honeycomb core. Greater strength can be gained through the use of doors that have internal 20-gauge steel ribs.
- Lighter-skinned steel doors may be used with modification. The modification is the addition of a 14-gauge steel sheet to either side of the door. The installation of the steel should be with 1/4-inch x 1-1/4-inch self-tapping screws with hexagon washer heads attached at 6 inches o.c. along the perimeter of the sheathing and 12 inches o.c. in the field. The internal door construction should meet the specifications listed above.
- Site-built sliding doors constructed of two layers of 3/4-inch plywood and an 11-gauge steel plate attached to the exterior face of the door with 1/4-inch x 1-1/4-inch self-tapping screws with hexagon washer heads attached at 6 inches o.c. along the perimeter of the sheathing and 12 inches o.c. in the field. These doors must be supported by "pockets" capable of transferring loads on the door to the shelter wall.

6.4.1.2 Single-Door Systems Greater Than 36 Inches Wide

A pressure test was performed on a single door 3 feet 8 inches wide (44 inches) and 7 feet tall. The door was constructed as described in the first bullet of

Section 6.4.1.1. The door was installed in a 14-gauge frame constructed within an 8-inch reinforced CMU wall and connected to the CMU with steel T-anchors spaced at 16 inches o.c.; the void between the frame and the masonry wall was grouted solid. The door was connected to the frame with five 4-1/2-inch heavyweight hinges. The latching hardware on the door tested was the single-lever-operated hardware (described in Section 6.4.3).

This door system did not withstand the pressure test and failed before reaching the design pressure of 1.75 psi. The door failed when the pressure reached 1.19 psi. The door deflected during the pressure test and buckled around the latching hardware. After this first test, the door could not be closed and secured. Further testing to identify door construction for 44-inch doors is required before design guidance may be given for these large, single doors.

NOTE

Heavy-gauge steel doors have been tested for resistance to wind pressures. Testing has shown that the weak link in available door products is the door hardware. At the time this manual was published, only one door/door hardware system resisted the pressures from a 250-mph wind at leeward wall surfaces (away from building corners); see Appendix F. Wind pressures can be reduced at building corners with an alcove that protects the door system from edge effects. See Section 6.4.3 for testing of door hardware systems

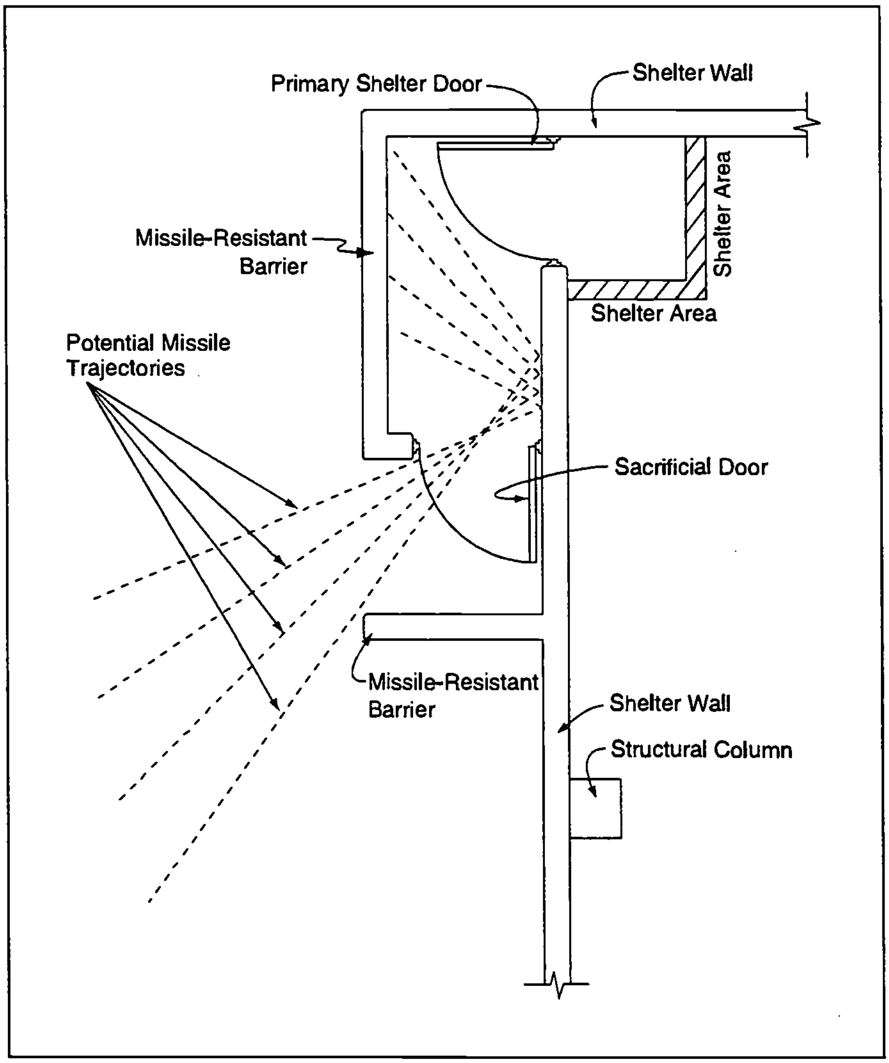
6.4.1.3 Double-Door Systems (With Center Mullion)

A double-door system (with a fixed center mullion) was tested for resistance to damage from wind pressures and missile impact. One door was equipped with a panic bar mechanism; the other was equipped with a single-action lever mechanism. This configuration was tested twice. The door configuration for these tests used two doors arranged in a swing-out configuration (a typical requirement for code-compliant egress). Each door was 3 feet wide and 7 feet tall and was constructed as described in the first bullet of Section 6.4.1.1. The doors were mounted in a 14-gauge steel frame with a 4-3/4-inch-deep frame with a 14-gauge center steel mullion. The mullion was bolted to the top of the frame and to a 12-gauge steel base plate at the sill with a 3/8-inch bolt at each location. The bolts extended from the front to the back of the mullion so as not to interfere with the doors when they were closed. The steel base plate was connected to the foundation below the sill with a 5/8-inch-diameter anchor bolt. The center mullion was reinforced with a T-shape 1/4 inch thick and 4 1/2 inches deep. The T-shape was welded to the back side of the mullion with 3-inch fillet welds at 9 inches o.c. Finally, the frame was attached to an 8-inch, fully reinforced, CMU wall with steel T-anchors spaced 16 inches o.c., and the void between the frame and the masonry wall was grouted solid. No grout was placed in the center mullion.

The double-door system was tested with pressures associated with the 250-mph design wind and for the 15-lb design missile. This door configuration was tested to a pressure of 1.37 psi, but was not tested to failure. However, deflection of the double-door system during the pressure testing damaged one of the lock mechanisms (this is discussed further in Section 6.4.3). During the missile impact tests, one door withstood the impacts and remained closed, but the hardware on that door (the panic bar hardware) was no longer operational. The second door (with the single-action lever hardware) was damaged such that the door was pushed through the frame, causing a rotation in the center mullion. For life-safety considerations, these results meet the missile impact criteria since the missile did not enter the shelter area. However, when functionality is a requirement (such as in the Dade County Florida impact test criteria), this result does not meet the impact requirements.

Therefore, double-door systems require further testing before a system capable of resisting the missile impact tests can be specified. Designers who wish to use double-door systems should use an alcove system that prevents direct missile impacts on the double-doors (see Figure 6-8) or should test double-door systems and hardware with heavier construction than those described in this section before installing the doors in a shelter in Wind Zone IV.

Figure 6-8
The door of the shelter in Case Study I (Appendix C) is protected by a missile-resistant barrier. Note: the shelter roof extends past the shelter wall and connects to the top of the missile-resistant barrier to prevent the intrusion of missiles traveling vertically.



6.4.2 Door Frames

Sixteen-gauge steel door frames in either a welded or knockdown style are known to be adequate to carry design wind and impact loads on a single door. Care must be taken in the installation of the frame so that it works properly and does not hinder the rest of the shelter construction. Frames used in stud construction must be attached to the MWFRS. This attachment is achieved with #8 x 3-inch screws, placed 6 inches o.c., installed through the jamb of the frame into the studs that make the rough opening of the door. Frames used in masonry construction are connected to the structure with T-anchors. It is critical that the T-anchors be bent at the internal edge of the masonry so that the tail of the anchor does not interfere with the placement of reinforcing steel and pea-gravel concrete.

Frames for large single doors should be constructed of at least 14-gauge steel. Frames for double-door systems should be constructed of at least 14-gauge steel frames and use a 14-gauge, steel center mullion as described in Section 6.4.1.3. The double-door system used in the testing secured the mullion to a 12-gauge steel base plate. The base plate was secured to the concrete below the doorsill with a single 5/8-inch diameter bolt. However, displacement and twisting of the center mullion (and base plate) occurred during the missile impact tests. If two bolts are used instead of one, this frame assembly should withstand the impact from the design missile and remain functional without loss of shape.

6.4.3 Door Hardware

Door hardware was found to be another limiting element in the ability of doors to withstand wind and missile impact loads. Although some standard door hardware was capable of withstanding wind pressures associated with Zones II and III (see Figure 2-2), none of the conventional hardware tested during the preparation of FEMA 320 (for wind zone IV on Figure 2-2) was capable of carrying design wind loads or withstanding missile impacts when the impact occurred near the lock set or door handle mechanism. Hence, testing found that steel doors with supplemental latching mechanisms near the top and the bottom are required to carry design wind loads and to prevent an inward-swinging door from being knocked open with a well-placed missile. Three latching mechanisms are required so that, if a debris impact close to one destroys it, two latches will be left to carry the wind loads.

WARNING

Maintenance problems have been encountered with some 3-point latching systems currently in use. If the door system uses a latch that engages a floor-mounted catch mechanism, proper maintenance is required if the latch is to function properly. Lack of maintenance may lead to premature failure of the door hardware during a high-wind event.

6.4.3.1 Single-Latch Mechanisms

Previous testing of latching and locking mechanisms consisted of testing an individual latch/lock cylinder or a mortised latch with a throw bolt locking function. In each case, tests proved that these locks, when used alone (without supplemental locks) did not pass the wind pressure and missile impact tests.

NOTE

All doors tested by FEMA prior to January 2000 were equipped with latching mechanisms composed of three, individually activated deadbolt closures. Between January and May 2000, multiple latching mechanisms activated by a single lever or by a panic bar release mechanism were tested.

Further testing proved that doors with these latching mechanisms and two additional mortised, cylindrical dead bolts (with solid 1/2-inch-thick steel throw bolts with a 1-inch throw into the door jamb) above and below the original latch would meet the requirement of the wind pressure and missile impact tests. It is important to note, however, that hollow deadbolts containing rod inserts failed the tests.

However, the use of a door with three individually operated latching mechanisms may conflict with code requirements for egress for areas with large occupancies. Sections 6.4.3.2 and 6.4.3.3 discuss door hardware operated with panic hardware and single-action lever hardware. Additional guidance on door and egress requirements is provided in Section 6.4.4.

6.4.3.2 Latching Mechanisms Operated With Panic Hardware

An extensive search was performed to locate three-point latching systems operated from a single panic bar capable of resisting the wind pressures and missile impacts specified in this chapter. A single system was selected and tested. This system consists of a panic-bar-activated headbolt, footbolt, and mortised deadbolt. The headbolt and footbolt are 5/8-inch stainless steel bolts with a 1-inch projection (throw) at the top and bottom and are encased in stainless steel channels. Each channel is attached to the door with a mounting bracket. The headbolt and footbolt assembly can be mounted inside the door or on the exterior of the door; only the externally mounted assembly was tested. The mortised lock complies with ANSI/BHMA 115.1 standard mortise lock and frame preparation (1-1/4-inch x 8-inch edge mortise opening with mounting tabs). All three locking points were operated by a single action on the panic bar.

This hardware was used for the double-door tests discussed in Section 6.4.1.3. Each of the doors was fitted with the panic bar hardware and three-point latches. This system was tested to 1.37 psi without failure. The system also passed the missile impact test, and the door remained closed; however, the hardware was not operational after the test.

6.4.3.3 Latching Mechanisms Operated With Single-Action Lever Hardware

A three-point latching system operated with a single-action lever was also tested for its ability to resist the wind pressures and missile impacts specified in this chapter. This system meets ANSI/BHMA A156.13 Operational Grade 1 and fits a modified ANSI 115.1 door and frame preparation. The mortise case is heavy-duty wrought steel with a lever-activated latch and a 1-inch solid bolt with a 1-inch throw. Operation of the latch activates two 1-inch x 3/8-inch solid hookbolts. One hookbolt is located 1 foot 4 inches above the deadbolt and the other is located 1 foot 4 inches below the deadbolt.

This hardware system was used in the large single-door tests and the double-door tests discussed in Sections 6.4.1.2 and 6.4.1.3, respectively. During the pressure test on the 44-inch single door, the deflection of the door resulted in the hookbolts (engaged in the frame) pulling out of the door itself. During the double-door tests, this hardware was damaged during the pressure test when the top hookbolt failed at its connection to the door (securing screws failed in shear). During the missile impact tests, the hardware resisted the missile impacts until a missile shot caused the center mullion to rotate, releasing the throw from the mullion. Further testing is required to determine whether the hardware or door can be modified to stabilize the hookbolts and prevent failure.

6.4.4 Doors and Egress Requirements

All doors must have sufficient points of connection to their frame to resist design wind pressure and impact loads. Each door should be attached to its frame with six points of connection (three connections on the hinge side and three connections on the latch side). Model building codes and life safety codes often include strict requirements for securing doors in public areas (areas with assembly classifications). This guidance often requires panic bar hardware, single-release mechanisms, or other hardware requirements. For example, the IBC and the NFPA life safety code require panic bar hardware on doors for assembly occupancies of 100 persons or more. The design professional will need to establish what door hardware is required and what hardware is permitted.

Furthermore, most codes will not permit primary or supplemental locking mechanisms that require more than one action to achieve egress, such as dead bolts, to be placed on the door of any area with an assembly occupancy classification, even if the intended use would only be during an extreme-wind event. This restriction is also common for school occupancy classifications.

These door hardware requirements affect not only shelter areas, but also rooms and areas adjacent the shelter. For example in a recent project in North Carolina, a school design was modified to create a shelter area in the main hallway. Structurally, this was not a problem; the walls and roof systems were designed to meet the wind pressure and missile impact criteria presented in this manual. The doors at the ends of the hallway also were easily designed to meet these criteria. However, the doors leading from the classrooms to the hallway were designed as rapid-closing solid doors without panic hardware in order to meet the wind pressure and missile impact criteria. This configuration was not a problem when the students were in the hallway that functioned as a shelter, but it was a violation of the code for the normal use of the classrooms. The designer was able to meet the door and door hardware requirements of the code for the classrooms by installing an additional door in each classroom that did not lead to the shelter area, thereby providing egress that met the requirements of the code.

Another option for protecting doors from missile impacts and meeting the criteria of this manual is to provide missile-resistant barriers. The shelter designs presented in Appendixes C and D of this manual use alcoves to protect doors from missile impacts. A protective missile-resistant barrier and roof system should be designed to meet the design wind speed and missile impact criteria for the shelter and maintain the egress width provided by the door itself. If this is done, the missile impact criteria for the door and code egress requirements for the door are satisfied. Although the wind pressures at the door should be reduced by the presence of the alcove, significant research to quantify the reduction has not been performed. Therefore, the door should be designed to resist wind pressures from the design wind. See Figure 6-8 for an example of an alcove used to protect a door assembly from missile impact.

Finally, the size and number of shelter doors should be determined in accordance with applicable fire safety and building codes. If the community or governing body where the shelter is to be located has not adopted current fire safety or model building codes, the requirements of the most recent edition of a model fire safety and model building code should be used.

6.5 Windows

Natural lighting is not required in small residential shelters; therefore, little testing has been performed to determine the ability of windows to withstand the debris impacts and wind pressures currently prescribed. However, for non-residential construction, some occupancy classifications require natural lighting. Furthermore, design professionals attempting to create aesthetically pleasing buildings are often requested to include windows and glazing in building designs. Glazing units can be easily designed to resist high-wind pressures and are routinely installed in high-rise buildings. However, the controlling factor in extreme-wind events, such as tornadoes and hurricanes, is protection of the glazing from missile perforation (the passing of the missile through the window section and into a building or shelter area).

NOTE

No window or glazing system tested for resistance to missile impact has met the missile impact criteria recommended in this manual.

Polycarbonate sheets in thicknesses of 3/8 inch or greater have proven capable of preventing missile perforation. However, this material is highly elastic and extremely difficult to attach to a supporting window frame. When these systems were impacted with the representative missile, the deflections observed were large, but were not measured.

For this manual, window test sections included Glass Clad Polycarbonate (2-ply 3/16-inch PC with 2-ply 1/8-inch heat-strengthened glass) and four-layer and five-layer laminated glass (3/8-inch annealed glass and 0.090 PVB laminate). Test sheets were 4 feet x 4 feet and were dry-mounted on neoprene in a heavy steel frame with bolted stops. All glazing units were impact-tested with the representative missile, a 15-lb wood 2x4 traveling at 100 mph.

Summarizing the test results, the impact of the test missile produced glass shards, which were propelled great distances and at speeds considered dangerous to shelter occupants. Although shielding systems can contain glass spall, their reliability is believed to degrade over time. Further testing of the previously impacted specimen caused the glass unit to pull away from the frame.

Testing indicates that glass windows in any configuration are undesirable for use in tornado shelters. The thickness and weight of the glass systems required to resist penetration and control glass spall, coupled with the associated expense of these systems, make them impractical for inclusion in shelter designs.

It is therefore recommended that glazing units subject to debris impacts not be included in shelters until products are proven to meet the design criteria. Should the shelter design require windows, the designer should have a test performed consistent with the impact criteria. The test should be performed on the window system with the type and size of glass specified in the design and mounted in the actual frame as specified in the design. A "PASS" on the test must agree with the following: 1) the missile must not perforate the glazing, 2) the glazing must remain attached to the glazing frame, and 3) glass fragments or shards must remain within the glazing unit. It is important to note that glass block is also not acceptable. Glass block, set in beds of unreinforced lime-rich mortar, offers little missile protection.

7 Additional Considerations

Chapters 5 and 6 discuss wind load and debris impact design criteria specific to wind shelters. This chapter discusses additional issues that should be considered in the design of wind shelters and buildings in general. These issues include flood and seismic hazards, fire protection and life safety, permitting and code compliance, and quality assurance/quality control,

7.1 Flood Hazard Considerations

The designer should investigate all sources of flooding that could affect the use of the shelter. These include floods up to and including the 500-year flood; any flood of record; flooding from storm surge (in coastal areas); and flooding from local drainages. If it is not possible to locate a shelter outside an area subject to the flooding described above, special precautions must be taken to ensure the safety and well-being of anyone using the shelter. The lowest floor of the shelter must be elevated above the flood elevation from any of the flooding sources described. All utilities or services provided to the shelter must be protected from flooding as well.

NOTE

The lowest floor of a shelter located in the SFHA must be elevated above the 500-year flood elevation or elevated to the BFE + 1 foot, whichever is higher.

A shelter in a floodprone area must be properly equipped to meet any emergency medical, food, and sanitation needs during the time the occupants could be isolated by flooding. Access to the shelter must be maintained during flooding conditions. If access is not possible by ground transportation during flooding, alternative access must be provided. An example of how alternative access can be achieved is the installation of a helicopter pad that is above the flood levels. In all cases, both the designer and the owner will need to work with local and state emergency managers to ensure that these special requirements are met, both in the shelter design and construction and in emergency operation procedures.

7.2 Seismic Hazard Considerations

When a shelter is in a seismically active area as defined by the IBC, ASCE 7-98, or FEMA's NEHRP provisions, the structure should be checked for resistance to seismic forces. However, wind loads, as described in this manual, and earthquake (seismic) loads differ in the mechanics of loading. The difference is created by how the load is applied. In a wind event, the load is applied to the exterior of the envelope of the structure. Typically, internal building elements that are not part of the MWFRS of the building will not receive load unless there is a breach of the building envelope. Earthquakes induce loads based on force acceleration relationships. This relationship requires that all objects of mass develop loads. Therefore, all structural elements and all non-structural components within, and attached to, the structure will be loaded. As a result, seismic loading requires both exterior building elements and internal building elements (including non-loadbearing elements and fixtures) to be designed for the seismically induced forces.

Another important seismic consideration for the designer is the assumed response of the structure during an event. Buildings are designed to remain elastic during a wind event—elastic in the sense that no permanent deformation of any of the structural members will occur. For earthquakes, this is not the case. Design for earthquakes is based on a two-earthquake scenario. The first earthquake is the common earthquake that can occur many times in the life of a structure and the second is the larger, rare earthquake. The design process requires that the structure remain elastic for the common earthquake. But for the rare earthquake, permanent deformation is allowed as long as it does not result in structural collapse of the building. Building elements that can "stretch and bend" give a structure the ability to withstand a large earthquake without the economic penalty of having to accommodate the rare earthquake without any permanent deformation.

7.2.1 Design Methods

After earthquakes in the 1920s and 1930s in California, engineers began to recognize the need to account for the lateral seismic-induced loads on structures. The first seismic codes calculated lateral seismic-induced loads using a percentage of the weight of the structure. This allowed common analysis procedures to be used. This method has been retained and is seen in today's building codes. It is commonly called the equivalent static force method. Over the years, this percentage coefficient has been refined and put on a more rational basis derived from the dynamic analysis of structures.

There are cases in which a more complicated dynamic analysis procedure is required. This dynamic analysis is common in the design and construction of very tall, irregular structures. The structures are considered irregular in that they are not rectangular or cube-like. They may have wings or appendages like an "L" or they may be "cross-shaped" structures. Figure 7-1 shows examples of buildings with an irregular shape.

The dynamic analysis procedure for these types of structures consists of three parts:

1. a time history analysis
2. a response spectrum is developed
3. a modal analysis of the final structure

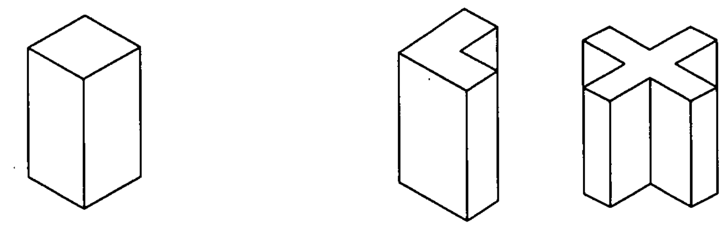


Figure 7-1
Examples of buildings with regular and irregular shapes.

Unless a seismic event has occurred and is documented at the exact building site, some sort of computed ground movement must be developed. This can be done in several ways. One is to use existing earthquake records and average several of them to produce a composite ground motion. Figure 7-2 is an actual graphical representation of a time response of the ground during a seismic event.

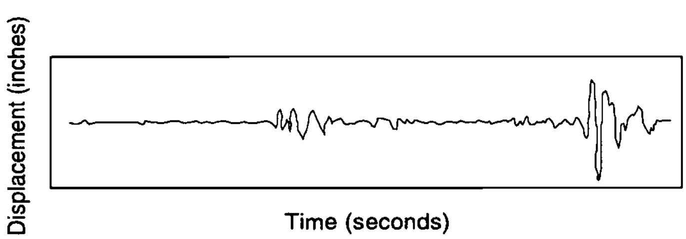


Figure 7-2
Time response of ground during seismic event.

Another way is to synthetically generate this motion using models of geologic phenomena and soil conditions. In either case, the result is a description of the movement and acceleration of the ground. Once this acceleration is defined, the acceleration is used as input in a single-degree-of-freedom system, illustrated in Figure 7-3. The single-degree-of-freedom system is a model of the building system with mass from floors and roof systems consolidated together to represent the building as a mass (M) supported by vertical building elements, with stiffness (k), acted upon by a lateral force (F) representative of the ground acceleration.

The stiffness (k) of the system can be varied to change the period of the building response to the applied lateral force. When this is done, a plot is made of the acceleration versus the period of the structure (see Figure 7-4). This type of plot is known as a Response Spectrum for the induced earthquake motion and illustrates the elastic structural system response to a particular earthquake motion.

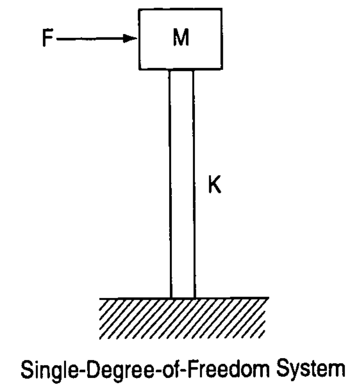


Figure 7-3
Example of single-degree-of-freedom system.

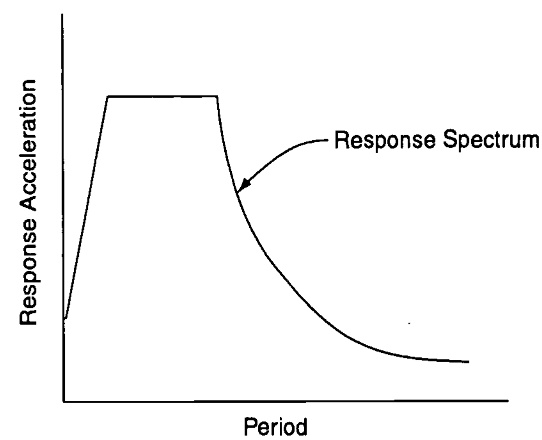


Figure 7-4
Acceleration vs. period of structure.

The last step in the dynamic analysis is to perform a modal analysis on the actual building. This type of analysis provides the motion of the building in terms of a single-degree-of-freedom system. Therefore, the response spectrum can be input into the modal analysis to give the building's response to the earthquake.

Both the static method and the dynamic method result in lateral forces induced on the structure. The geographic region of the country in which the shelter is located will dictate which analysis should be used. Once the forces are calculated, they can be input into the load combinations (as seismic load E) used for the design of the shelter.

7.2.2 Code Development

Earthquake codes are under continual refinement as new data become available. This continual refinement attempts to give more accurate models of how a structure responds to ground motion. Seismic events, like wind events, are constantly occurring and continue to test buildings constructed to recently improved codes and standards. An earthquake provides a test for the current procedures; after every event, those procedures are reviewed to ensure they are acting as intended.

An example of code development is the recent acknowledgment that seismic events occurring on the west and east coasts are not expected to be the same type of seismic event. On the west coast, the difference between the common earthquake and the rare earthquake is small. Design codes assume that the rare earthquake is only 50 percent larger than the common earthquake. On the east coast, this is not the case. In this region, the rare earthquake can be as much as 400 percent larger than the common earthquake. Therefore, prior to the release of the 2000 IBC, western U.S. design codes did not fit well to eastern U.S. earthquake requirements.

This poor fit has led to refinements in seismic design procedures. The new procedures attempt to provide a process for evaluating the response of a building when it begins to deform from seismic loads. This approach is needed to ensure that the structure can stretch and bend to resist the rare earthquake. Whereas, in the western U.S. this is ensured because of the minimal difference betweem the two different earthquakes, this cannot also be assumed in the eastern U.S.

7.2.3 Other Design Considerations

All the elements of the structure must be evaluated for earthquake forces. Not only are the exterior walls loaded, but the interior walls can also receive substantial out-of-place loads. For wind loading, these interior building components are not usually considered, although most codes require interior walls to be designed for some lateral pressure. Often, seismically induced forces are larger than the code-specified lateral wind pressures and, as a result, govern the design. Therefore, the design of these elements and their connections to the main structure are essential to a complete design—one in which both non-structural and structural elements are considered.

Earthquake requirements considered in the design of a shelter can enhance the lateral resistance of the structure to wind loads. For example, seismic loads tend to govern the designs of "heavy" structures constructed with concrete or masonry walls and concrete slab or roofs. In "lighter" structures constructed from framing and light structural systems supporting lightweight (metal or wood) roof systems, wind loads tend to govern. But even if wind loads govern, consideration should be given to the calculated seismic loads to allow the structure to deform without immediate failure. This ability gives the structure reserve capacity that can be used in severe-wind events.

7.3 Other Hazard Considerations

It is important that the designer consider other hazards at the building site, in addition to the wind, flood, and seismic hazards already considered. One such consideration is the location of a shelter on a building site with possible physical hazards (e.g., other building collapses or heavy falling debris). These siting and location issues are discussed in Chapter 4, and design guidance is provided in Section 6.3.

Another consideration is the presence of a hazardous material (HAZMAT) threat on site. Older buildings that are retrofitted for shelter use should be inspected for hazardous materials that may be stored near the shelter (e.g., gasoline, chlorine, or other chemicals) or that may have been used in the construction of the surrounding building (e.g., lead paint or asbestos). For example, asbestos may become airborne if portions of the surrounding building are damaged, resulting in the chemical contamination of breathable air. Live power lines, fire, and gas leaks are also shelter design concerns that may need to be addressed at some shelter sites. For example, the case study in Appendix D (Sheet P-1) shows how a gas line, required for gas service to the shelter area when in normal daily use, was fitted with an automatic shutoff valve. This precaution greatly reduces the risk of a gas-induced fire occurring while the shelter is occupied.

CROSS-REFERENCE

The hazard associated with a live gas line servicing a shelter is addressed in the case study in Appendix D, on Sheet P-1 of the design plans.

7.4 Fire Protection and Life Safety

The shelter must comply with the fire protection and life safety requirements of the model building code, the state code, or the local code governing construction in the jurisdiction where the shelter is constructed. For single-use high-wind shelters, the model building codes, life safety codes, and engineering standards do not indicate square footage requirements or occupancy classifications. For multi-use high-wind shelters, the codes and standards address occupancy classifications and square footage requirements for the normal use of the shelter. The shelter designer is advised to comply with all fire and life safety code requirements for the shelter occupant load and not the normal use load; the shelter occupancy load is typically the controlling occupancy load. Chapter 8, Section 8.2, discusses the recommended square footage requirements for tornado and hurricane shelters.

Guidance and requirements concerning fire protection systems may be found in the model building codes and the life safety codes. Depending on the occupancy classification of the shelter (in normal use), automatic sprinkler systems may or may not be required. For many shelters, an automatic sprinkler system will not be required. However, when automatic sprinkler systems are not required and fire extinguishers are used, all extinguishers should be mounted on the surface of the shelter wall. In no case should a fire extinguisher cabinet or enclosure be recessed into the interior face of the exterior wall of the shelter. This requirement is necessary to ensure that the integrity of the shelter walls is not compromised by the installation of fire extinguishers. Finally, any fire suppression system specified for use within shelters should be appropriate for use in a closed environment with human occupancy. If a fire occurs during a tornado or hurricane, it may not be possible for occupants of the shelter to ventilate the shelter immediately after the discharge of the fire suppression system.

7.5 Permitting and Code Compliance

Before construction begins, all necessary state and local building and other permits should be obtained. Because model building codes and engineering standards do not address the design of a tornado or hurricane shelter, the design professional should meet with the local code official to discuss any concerns the building official may have regarding the design of shelter. This meeting will help ensure that the shelter is properly designed and constructed to local ordinances or codes.

Complete detailed plans and specifications should be provided to the building official for each shelter design. The design parameters used in the structural design of the shelter, as well as all life safety, ADA, mechanical, electrical, and plumbing requirements that were addressed, should be presented on the project plans and in the project specifications.

Egress requirements should be based on the maximum occupancy of the shelter area. This will likely occur when the designer calculates the occupancy load based on the 5 ft^2 or 10 ft^2 per person recommended in Section 8.2 for tornado and hurricane shelters, respectively. For multi-use shelters, reaching the maximum occupancy will be a rare event. For life safety considerations, egress points for the shelter area should be designed to the maximum possible occupancy until a code or standard governing the design of shelters is developed. As a result, the design professional will likely have difficulty providing doors and egress points with hardware (specifically latching mechanisms) that comply with code and resist the design missile impact criteria presented earlier in this chapter. Design professionals who are limited to door hardware that is acceptable to the building official but that does not meet the impact resistance criteria should refer to Section 6.4.4 and Figure 6-8 for guidance on the use of missile-resistant barriers to protect doors from debris impact.

Regarding code requirements not related to life safety or structural requirements—typically those for mechanical, electrical, and plumbing systems—the designer should design for the normal use of a multi-use shelter unless otherwise directed by the authority having jurisdiction. It would not be reasonable to consider the additional cost of and need for providing additional mechanical, electrical, and plumbing equipment and facilities for the high-occupancy load that would occur only when the shelter is providing protection from a tornado or hurricane. Shelters designed to the criteria in this manual are for short-duration use, and the probability of their use at maximum occupancy is low.

NOTE

The square footage recommendations for shelters designed to meet the criteria presented in this manual are as follows:

Tornado shelters: 5 ft^2 per person

Hurricane shelters: 10 ft^2 per person

These square footage recommendations are discussed in Section 8.2.

7.6 Quality Assurance/Quality Control Issues

Because a tornado or hurricane shelter must perform well during extreme conditions, quality assurance and quality control for the design and construction of the shelter should be at a level above that for normal building construction. Design calculations and shop drawings should be thoroughly scrutinized for accuracy. When the design team is satisfied that the design of the shelter is acceptable, a registered design professional should prepare the quality assurance plan for the construction of the shelter.

The quality assurance plan should be based on the Special Inspection Requirements listed in Sections 1704, 1705, and 1706 of the IBC; however, because of the design wind speeds involved, exceptions that waive the need for quality assurance when elements are prefabricated should be not allowed. The IBC recommends using these special inspections and quality assurance program when the design wind speeds are in excess of 110–120 mph (3-second gust), depending on exposure or if the building is in a high seismic hazard area. Sufficient information to ensure that the shelter is built in accordance with the design and the performance criteria of this manual should be provided by the design professional. The quality of both construction materials and methods should be ensured through the development and application of a quality control program.

A typical quality assurance plan should require that special inspections be performed on the following building elements:

- roof cladding and framing connections
- wall-to-roof connections and wall-to-floor connections
- roof and floor diaphragm systems, including framing, collectors, struts, and boundary elements
- vertical and lateral MWFRS, including braced frames, moment frames, and shearwalls

- connections of the MWFRS to the foundation
- all prefabricated elements and their connections to other shelter components during on-site assembly
- fabrication and installation of components and assemblies required to meet the missile impact resistance requirements of this chapter

To ensure that the elements described above are properly inspected, the quality assurance plan should identity the following:

- the elements and connections of the MWFRS that are subject to inspection
- the special inspections and testing to be provided according to IBC Section 1704, including the applicable references standards provided referred to in the IBC
- the type and frequency of testing required
- the type and frequency of special inspections required
- the required frequency and distribution of testing and special inspection reports
- the structural observations to be performed
- the required frequency and distribution of structural observation reports

8 Human Factors Criteria

Human factors criteria for the community shelters build on existing guidance provided in Chapters 5 and 6. Although existing documents do not address all the human factors involved in the design of high-wind shelters, they provide the basis for the criteria summarized in this chapter. If shelters are located in areas at risk for both tornadoes and hurricanes, the design should incorporate the human factor criteria for hurricanes. These criteria are detailed in the following sections.

8.1 Ventilation

Ventilation for a shelter should comply with the building codes or ordinances adopted by the local jurisdiction. Ventilation should be provided to the shelter area through either the floor or the ceiling. Although horizontal ventilation openings may be easier to design and construct, vertical ventilation openings have a smaller probability of being penetrated by a missile. Nevertheless, a protective shroud or cowling that meets the missile impact requirements of Chapters 5 and 6 should be provided to protect any ventilation openings in the shelter that are exposed to possible missile impacts, such as the point where ductwork for a normal-use ventilation system penetrates the wall or roof of the shelter.

The ventilation system for both single- and multi-use shelters must be capable of providing the minimum number of air changes required by the building code for the shelter's occupancy classification. For single-use shelters, 15 ft^3 per person per minute is the minimum air exchange recommended—this recommendation is based on guidance outlined in the International Mechanical Code (IMC). For multi-use shelters, the design of mechanical ventilation systems is recommended to accommodate the air exchange requirements for the occupancy classification of the normal use of the shelter area. Although the ventilation system may be overwhelmed in a rare event when the area is used as a shelter, air exchange will still take place. The designer should still confirm with the local building official that the ventilation system may be designed for the normal-use occupancy. In the event the community where the shelter is to be located has not adopted a model building and/or mechanical code, the requirements of the most recent edition of the IBC are recommended.

Passive means of ventilation may be used as long as the building code requirements for normal use are met. Ventilation may be accomplished with passive air systems using ducts that open to an outside air supply. For example, the 1997 Uniform Building Code (UBC) provisions for natural ventilation requires exterior openings with a minimum area of 1/20 of the total floor area. When complying with code requirements for openings, the designer needs to protect the openings to prevent windborne debris from entering the shelter.

However, any buildings that support hospitals or other life-critical operations should consider appropriate design, maintenance, and operational plans that ensure continuous operation of all mechanical equipment during and after a tornado or hurricane. In these instances, a failure of the air-handling system may have a severe effect on life safety. For these types of facilities, protecting the backup power supply that provides power to the ventilation system of the shelter is recommended.

8.2 Square Footage/Occupancy Requirements

Occupancy recommendations for tornado and hurricane shelter design are provided in this section. The recommended minimums are 5 ft^2 per person for tornado shelters and 10 ft^2 per person for hurricane shelters. Additional guidance is provided in Sections 8.2.1 and 8.2.2 for square footage requirements other than the minimum requirements.

The shelter designer should be aware of the occupancy requirements of the building code governing the construction of the shelter. The occupancy loads in the building codes have historically been developed for life safety considerations. Most building codes will require the maximum occupancy of the shelter area to be clearly posted. Multi-use occupancy classifications are provided in the IBC and state and local building codes. Conflicts may arise between the code-specified occupancy classifications for normal use and the occupancy needed for sheltering. For example, according to the IBC, the occupancy classification for educational use is 20 ft^2 per person; however, the recommendation for a tornado shelter is 5 ft^2 per person. Without proper signage and posted occupancy requirements, using an area in a school as a shelter can create a potential conflict regarding the allowed numbers of persons in the shelter. If both the normal maximum occupancy and the shelter maximum occupancy are posted, and the shelter occupancy is not based on a minimum less than the recommended 5 ft^2 per person, the shelter design should be acceptable to the building official. The IBC and the model building codes all have provisions that allow occupancies as concentrated as 5 ft^2 per person.

8.2.1 Tornado Shelter Square Footage Recommendations

Section 8.2 recommends a minimum of 5 ft^2 per person for tornado shelters. However, other circumstances and human factors may require the shelter to accommodate persons who require more than 5 ft^2. Square footage recommendations for persons with special needs are presented below; these recommendations are the sáme as those provided in the FEMA 1999 *National Performance Criteria for Tornado Shelters*:

- 5 ft^2 per person adults standing
- 6 ft^2 per person adults seated
- 5 ft^2 per person children (under the age of 10)
- 10 ft^2 per person wheelchair users
- 30 ft^2 per person bedridden persons

8.2.2 Hurricane Shelter Square Footage Recommendations

Section 8.2 recommends a minimum of 10 ft^2 per person for hurricane shelters (for a hurricane event only—an event expected to last less than 36 hours). This square footage requirement is a result of discussions among the Project Team and the Review Committee, who considered many issues regarding sheltering, including the recommendations of American Red Cross (ARC) Publication No. 4496. The ARC publication recommends the following minimum floor areas (Note: the ARC square footage criteria are based on long-term use of the shelter, i.e., use of the shelter both as a refuge area during the event and as a recovery center after the event):

- 20 ft^2 per person for a short-term stay (i.e., a few days)
- 40 ft^2 per person for a long-term stay (i.e., days to weeks)

Again, the designer should be aware that there can be conflicts between the occupancy rating for the intended normal use of the shelter and the occupancy required for sheltering. This occupancy conflict can directly affect egress requirements for the shelter. For example, for a 5,000-ft^2 proposed shelter area, the normal occupancy load is 5,100/20 = 255 people, while the shelter occupancy load is 5,100/10 = 510 people. For both educational and shelter uses, the IBC requires 0.20 inch of egress per person for buildings not equipped with a sprinkler system. For normal (educational) use, this calculates to 51 inches of required egress and, because of code, a minimum of two doors. Therefore, two 32-inch doors (64-inch total net egress) should be provided. For shelter use, the requirement is for 102 inches and a minimum of three doors. Therefore, three 36-inch doors (108-inch total net egress) should be provided. Although guidance concerning code compliance is provided in Chapter 6 of this manual, the conflicts between these two occupancy requirements for egress must be resolved with state and/or local officials. Future code requirements concerning occupancies and egress may address extreme events and temporary circumstances.

8.3 Distance/Travel Time and Accessibility

The shelter designer should consider the time required for all occupants of a building or facility to reach the shelter. The National Weather Service (NWS) has made great strides in predicting tornadoes and hurricanes and providing warnings that allow time to seek shelter. For tornadoes, the time span is often short between the NWS warning and the onset of the tornado. This manual recommends that a tornado shelter be designed and located in such a way that the following access criteria are met: all potential users of the shelter should be able to reach it within 5 minutes, and the shelter doors should be secured within 10 minutes. For hurricane shelters, these restrictions do not apply, because warnings are issued much earlier, allowing more time for preparation.

Travel time may be especially important when shelter users have disabilities that impair their mobility. Those with special needs may require assistance from others to reach the shelter; wheelchair users may require a particular route that accommodates the wheelchair. The designer must consider these factors in order to provide the shortest possible access time and most accessible route for all potential shelter occupants.

Access is an important element of shelter design. If obstructions exist along the travel route, or if the shelter is cluttered with non-essential equipment and storage items, access to the shelter will be impeded. It is essential that the path remain unencumbered to allow orderly access to the shelter. Hindering access in any way can lead to chaos and panic. In addition, siting factors that affect access should be considered (see Chapter 4). For example, at a community shelter built to serve a residential neighborhood, parking at the shelter site may complicate access to the shelter; at a non-residential shelter, such as at a manufacturing plant, mechanical equipment can impede access.

CROSS-REFERENCE

Chapter 4 discusses how the siting of shelters can affect access routes and travel time.

Unstable or poorly secured structural or C&C elements could potentially block access if a collapse occurs that creates debris piles along the access route or at entrances. A likely scenario is an overhead canopy or large overhang that lacks the capacity to withstand high wind forces and collapses over the entranceway. Prior to collapse, these entranceways and canopies may reduce wind pressures and protect any openings from windborne debris impacts. However, if they are not designed to withstand the design wind forces acting on the building, they may be damaged during a wind event and may prevent access to and egress from the shelter area. If canopies and overhangs are not designed for the design wind speed, they should either be retrofitted and reinforced or be removed.

8.3.1 Americans with Disabilities Act (ADA)

The needs of persons with disabilities requiring shelter space should be considered. The appropriate access for persons with disabilities must be provided in accordance with all Federal, state, and local ADA requirements and ordinances. If the minimum requirements dictate only one ADA-compliant access point for the shelter, the design professional should consider providing a second ADA-compliant access point for use in the event that the primary access point is blocked or inoperable. Additional guidance for compliance with the ADA can be found in many privately produced publications.

NOTE

For more information about providing for the needs of disabled persons during emergencies, refer to FEMA's United States Fire Administration publication *Emergency Procedures for Employees with Disabilities in Office Occupancies.*

The design professional can ensure that the operations plan developed for the shelter adheres to requirements of the ADA by assisting the owner/operator of the shelter in the development of the plan. All shelters should be managed with an operations and maintenance plan. Examples of Shelter Operations Plans are provided in Chapter 9 for community shelters intended to serve residential areas and for non-residential community shelters. Developing a sound operations plan is extremely important if compliance with ADA at the shelter site requires the use of lifts, elevators, ramps, or other considerations for shelters that are not directly accessible to non-ambulatory persons.

8.3.2 Special Needs

The use of the shelter also needs to be considered in the design. The design professional should be aware of the need of specific users for whom a shelter is being constructed. Occupancy classifications, life safety code, and ADA requirements may dictate the design of such elements as door opening sizes and number of doors, but use of the shelter by hospitals, nursing homes, assisted living facilities, and other special needs groups may affect access requirements to the shelter. For example, strict requirements are outlined in the IBC and the model codes regarding the provision of uninterruptable power supplies for life support equipment (e.g., oxygen) for patients in hospitals and other healthcare facilities.

In addition, strict requirements concerning issues such as egress, emergency lighting, and detection-alarm-communication systems are presented in Chapter 10 of the IBC and in the NFPA Life Safety Code (NFPA 101, 1997 Edition, Chapter 12) for health care occupancies. The egress requirements for egress distances, door widths, and locking devices on doors for health care occupancies are more restrictive than those for an assembly occupancy classification in non-health care facilities based on one of the model building codes for non-health care facilities. Additional requirements also exist for health care facilities that address automatic fire doors, maximum allowable room sizes, and maximum allowable distances to egress points. The combination of all these requirements could lead to the construction of multiple small shelters in a health care facility rather than one large shelter.

8.4 Lighting

For the regular (i.e., non-shelter) use of multi-use shelters, lighting, including emergency lighting for assembly occupancies, is required by all model building codes. Emergency lighting is recommended for community shelters. A backup power source for lighting is essential during a disaster because the main power source is often disrupted. A battery-powered system is recommended as the backup source because it can be located, and fully protected, within the shelter. Flashlights stored in cabinets are useful as secondary lighting provisions but should not be used as the primary backup lighting system. A reliable lighting system will help calm shelter occupants during a disaster. Failing to provide proper illumination in a shelter may make it difficult for shelter owners/operators to minimize the agitation and stress of the shelter occupants during the event. If the backup power supply for the lighting system is not contained within the shelter, it should be protected with a structure designed to the same criteria as the shelter itself.

Natural lighting provided by windows and doors is often a local design requirement but is not required by the IBC for assembly occupancies. At this time, no glazing system proposed to provide natural lighting for shelters meets the missile impact requirements presented in Chapter 6.

8.5 Occupancy Duration

The duration of occupancy of a shelter will vary depending on the intended event for which the shelter has been designed. Occupancy duration is an important factor that influences many aspects of the design process. Shelters designed to the criteria in this manual are designed to provide protection from a wind event only. The intent is to save lives during an actual tornado or hurricane. In the interest of developing cost-effective designs, some items that would have increased occupant comfort were not included in the recommended design criteria. However, examples of items that might help to make shelters more comfortable and functional during an event, and during post disaster recovery efforts, are discussed in Section 8.6 and are listed in the two sample operations plans in Chapter 9.

8.5.1 Tornadoes

Historical data indicate that tornado shelters will typically have a maximum occupancy time of 2 hours. Because the occupancy time is so short, many items that are needed for the comfort of occupants for longer durations (in hurricane shelters) are not recommended for a tornado shelter.

8.5.2 Hurricanes

Historical data indicate that hurricane shelters will typically have a maximum occupancy time of 36 hours. For this reason, the occupants of a hurricane shelter need more space and comforts than the occupants of a tornado shelter.

8.6 Emergency Provisions

Emergency provisions will also vary for different wind events. In general, emergency provisions will include food and water, sanitation management, emergency supplies, and communication equipment. A summary of these issues is presented in the following sections.

8.6.1 Food and Water

For tornado shelters, because of the short duration of occupancy, stored food is not a primary concern; however, water should be provided. For hurricane shelters, providing and storing food and water are of primary concern. As noted previously, the duration of occupancy in a hurricane shelter could be as long as 36 hours. Food and water will be required, and storage areas for them will need to be included in the design of the shelter. FEMA and ARC publications concerning food and water storage in shelters may be found on the World Wide Web at www.fema.gov and at www.redcross.org.

8.6.2 Sanitation Management

A minimum of two toilets are recommended for both tornado and hurricane shelters. Although the short duration of a tornado might suggest that toilets are not an essential requirement for a tornado shelter, the shelter owner/operator is advised to provide two toilets or at least two self-contained, chemical-type receptacles/toilets (and a room or private area where they may be used) for shelter occupants. Meeting this criterion will provide separate facilities for men and women.

Toilets will be needed by the occupants of hurricane shelters because of the long duration of hurricanes. The toilets will need to function without power, water supply, and possibly waste disposal. Although sanitation facilities may be damaged during a hurricane, siting of a shelter above a pump station (if required at a shelter site) would allow the system to have some capacity during the event. Whether equipped with standard or chemical toilets, the shelter should have at least one toilet for every 75 occupants, in addition to the two minimum recommended toilets.

8.6.3 Emergency Supplies

Shelter space should contain, at a minimum, the following safety equipment:

- flashlights with continuously charging batteries (one flashlight per 10 shelter occupants)
- fire extinguishers (number required based on occupancy type) appropriate for use in a closed environment with human occupancy, surface mounted on the shelter wall
- first-aid kits rated for the shelter occupancy
- NOAA weather radio with continuously charging batteries
- radio with continuously charging batteries for receiving commercial radio broadcasts
- supply of extra batteries to operate radios and flashlights
- audible sounding device that continuously charges or operates without a power source (e.g., canned air horn) to signal rescue workers if shelter egress is blocked

8.6.4 Communications

A means of communication other than landline telephone is recommended for all shelters. Both tornadoes and hurricanes are likely to cause a disruption in telephone service. At least one means of backup communication should be stored in or brought to the shelter. This could be a ham radio, cellular telephone, citizen band radio, or emergency radios capable of reaching police, fire, or other emergency service. If cellular telephones are relied upon for communications, the owners/operators of the shelter should install a signal amplifier to send/receive cellular signals from within the shelter. It should be noted that cellular systems may be completely saturated in the hours immediately after an event if regular telephone service has been interrupted.

Finally, the shelter should contain either a battery-powered radio transmitter or a signal-emitting device that can be used to signal the location of the shelter to local emergency personnel should occupants in the shelter become trapped by debris blocking the shelter access door. The shelter owner/operator is also encouraged to inform police, fire, and rescue organizations of the shelter location before an event occurs. These recommendations apply to both aboveground and belowground shelters.

8.7 Emergency Power

Shelters designed for both tornadoes and hurricanes will have different emergency (backup) power needs. These needs are based upon the length of time that people will stay in the shelters (i.e., shorter duration for tornadoes and longer duration for hurricanes). In addition to the essential requirements that must be provided in the design of the shelter, comfort and convenience should be addressed.

For tornado shelters, the most critical use of emergency power is for lighting. Emergency power may also be required in order to meet the ventilation requirements described in Section 8.1. The user of the shelter should set this requirement for special needs facilities, but most tornado shelters would not require additional emergency power.

For hurricane shelters, emergency power may be required for both lighting and ventilation. This is particularly important for shelters in hospitals and other special needs facilities. Therefore, a backup generator is recommended. Any generator relied on for emergency power should be protected with an enclosure designed to the same criteria as the shelter.

9 Emergency Management Considerations

Disaster preparedness is crucial to quick and effective responses to emergency situations. Potential owners and managers of tornado and hurricane shelters should be ready and able to open a shelter for immediate use in response to an extreme-wind event. The best way to accomplish this is to create a Shelter Operations Plan tailored to the needs of the intended users of the shelter. To help emergency managers and shelter owners and operators prepare Shelter Operations Plans, this chapter presents two types of plans in outline form: a Community Shelter Operations Plan with an accompanying Shelter Maintenance Plan in Sections 9.1 and 9.2, respectively, and a Commercial Building Shelter Operations Plan in Section 9.3. These plans should be considered as baseline plans that present the minimum information that should be contained within Shelter Operations Plans.

9.1 Community Shelter Operations Plan

Each shelter designed according to the guidance in this manual should have a Shelter Operations Plan. The plan should describe the difference between tornado watches and warnings, and hurricane watches and warnings, and clearly define the actions to be taken for each type of forecast. A Community Shelter Management Team composed of members committed to performing various duties should be designated. The following is a list of action items for the Community Shelter Operations Plan:

- The names and all contact information for the coordinators/managers detailed in Sections 9.1.1 through 9.1.7 should be presented in the beginning of the plan.
- A tornado or hurricane watch is issued by the National Weather Service (NWS) when a tornado or a hurricane is possible in a given area. When a watch is issued, the Community Shelter Management Team is on alert.
- A tornado or hurricane warning is issued when a tornado or hurricane has been sighted or indicated by weather radar. When a warning is issued, the Community Shelter Management Team is activated and begins performing the following tasks:
  - sending the warning signal to the community, alerting them to go to the shelter

- evacuating the community residents from their homes and to the shelter
- taking a head count in the shelter
- securing the shelter
- monitoring the storm from within the shelter
- after the storm is over, determining when conditions warrant allowing shelter occupants to leave and return to their homes
- after the storm is over, cleaning the shelter and restocking emergency supplies

A member of the Community Shelter Management Team can take on multiple assignments or roles as long as all assigned tasks can be performed effectively by the team member before and during a high-wind event.

The following team members would be responsible for overseeing the Community Shelter Operations Plan:

- Site Coordinator
- Assistant Site Coordinator
- Equipment Manager
- Signage Manager
- Notification Manager
- Field Manager
- Assistant Managers

Full contact information (i.e., home and work telephone, cell phone, and pager numbers) should be provided for all team members and their designated backups. The responsibilities of each of these team members are detailed in Sections 9.1.1 through 9.1.7. Suggested equipment and supplies for shelters are listed in Section 9.1.8 and Table 9.1. Appendix C includes an example of a Community Shelter Operations Plan.

9.1.1 Site Coordinator

The Site Coordinator's responsibilities include the following:

- organizing and coordinating the Community Shelter Operations Plan
- ensuring that personnel are in place to facilitate the Community Shelter Operations Plan

- ensuring that all aspects of the Community Shelter Operations Plan are implemented
- developing community education and training programs
- setting up first-aid teams
- coordinating shelter evacuation practice drills and determining how many should be conducted in order to be ready for a real event
- conducting regular community meetings to discuss emergency planning
- preparing and distributing newsletters to area residents
- distributing phone numbers of key personnel to area residents
- ensuring that the Community Shelter Operations Plan is periodically reviewed and updated as necessary

9.1.2 Assistant Site Coordinator

The Assistant Site Coordinator's responsibilities include the following:

- performing duties of the Site Coordinator when he/she is off site or unable to carry out his/her responsibilities
- performing duties as assigned by the Site Coordinator

9.1.3 Equipment Manager

The Equipment Manager's responsibilities include the following:

- understanding and operating all shelter equipment (including communications, lighting, and safety equipment, and closures for shelter openings)
- maintaining and updating, as necessary, the Shelter Maintenance Plan (see Section 9.2)
- maintaining equipment or ensuring that equipment is maintained year-round, and ensuring that it will work properly during a high-wind event
- informing the Site Coordinator if equipment is defective or needs to be upgraded
- purchasing supplies, maintaining storage, keeping inventory, and replacing outdated supplies
- replenishing supplies to pre-established levels following shelter usage

9.1.4 Signage Manager

The Signage Manager's responsibilities include the following:

- determining what signage and maps are needed to help intended shelter occupants get to the shelter in the fastest and safest manner possible
- preparing or acquiring placards to be posted along routes to the shelter throughout the community that direct intended occupants to the shelter
- ensuring that signage complies with ADA requirements (including those for the blind)
- providing signage in other languages as appropriate for the intended shelter occupants
- working with the Equipment Manager to ensure that signage is illuminated or luminescent after dark and that all lighting will operate if a power outage occurs
- periodically checking signage for theft, defacement, or deterioration and repairing or replacing signs as necessary
- providing signage that clearly identifies all restrictions that apply to those seeking refuge in the shelter (e.g., no pets, limits on personal belongings)

9.1.5 Notification Manager

The Field Manager's responsibilities include the following:

- developing a notification warning system that lets intended shelter occupants know they should proceed immediately to the shelter
- implementing the notification system when a tornado or hurricane warning is issued
- ensuring that non-English-speaking shelter occupants understand the notification (this may require communication in other languages or the use of prerecorded tapes)
- ensuring that shelter occupants who are deaf receive notification (this may require sign language, installation of flashing lights, or handwritten notes)
- ensuring that shelter occupants with special needs receive notification in an acceptable manner

9.1.6 Field Manager

The Field Manager's responsibilities include the following:

- ensuring that shelter occupants enter the shelter in an orderly fashion
- pre-identifying shelter occupants with special needs such as those who are disabled or who have serious medical problems
- arranging assistance for those shelter occupants who need help getting to the shelter (all complications should be anticipated and managed prior to the event)
- administering and overseeing first-aid by those trained in it
- providing information to shelter occupants during a high-wind event
- determining when it is safe to leave the shelter after a high-wind event

9.1.7 Assistant Managers

Additional persons should be designated to serve as backups to the Site Coordinator, Assistant Site Coordinator, Equipment Manager, Signage Manager, Notification Manager, and Field Manager when they are off site or unable to carry out their responsibilities.

9.1.8 Equipment and Supplies

Shelters designed and constructed to the criteria in this manual are intended to provide safe refuge from an extreme-wind event. These shelters serve a different function from shelters designed for use as long-term recovery shelters after an event; however, shelter managers may elect to provide supplies that increase the comfort level within the short-term shelters. Table 9.1 lists suggested equipment and supplies for community shelters.

9.2 Shelter Maintenance Plan

Each shelter should have a maintenance plan that includes the following:

- an inventory checklist of the emergency supplies (see Table 9.1)
- information concerning the availability of emergency generators to be used to provide power for lighting and ventilation
- a schedule of regular maintenance of the shelter to be performed by a designated party

Such plans will help to ensure that the shelter equipment and supplies are fully functional during and after tornadoes and hurricanes. The Shelter Maintenance Plan should be included as part of a Community, Commercial, or other Shelter Operations Plan.

Table 9.1 Shelter Equipment and Supplies

TYPE	EQUIPMENT/SUPPLIES
Communications Equipment	NOAA weather radios or receivers for commercial radio broadcasts if NOAA broadcasts are not available
	ham radios or emergency radios connected to the police or the fire and rescue systems
	cellular telephones (may not operate during a storm event and may require a signal amplifier to be able to transmit from within the shelter)
	battery-powered radio transmitters or signal emitting devices that can signal local emergency personnel
	portable generators with uninterrupted power supply (UPS) systems and vented exhaust systems
	portable computers with modem and internet capabilities
	public address systems
Emergency Equipment	a minimum of two copies of the Community Shelter Operations Plan
	flashlights and batteries
	fire extinguishers
	blankets
	pry-bars (for opening doors that may have been damaged or blocked by debris)
	trash receptacles
	trash can liners and ties
	tool kits
	heaters
First-Aid Supplies	adhesive tape and bandages in assorted sizes
	safety pins in assorted sizes
	latex gloves
	scissors and tweezers
	antiseptic solutions
	antibiotic ointments
	moistened towelettes
	non-prescription drugs (e.g., aspirin and non-aspirin pain relievers, anti-diarrhea medications, antacids, syrup of Ipecac, laxatives)
	smelling salts for fainting spells
	petroleum jelly
	eye drops
	wooden splints
	thermometers
	towels
	foldup cots
	first-aid handbooks
Water	adequate quantities for the duration of the particular storm
Sanitary Supplies	toilet paper
	moistened towelettes
	paper towels
	personal hygiene items
	disinfectants
	chlorine bleach
	plastic bags
	portable chemical toilet(s), when regular toilets are not contained in the shelter
Infant and Children Supplies (As Necessary	disposable diapers
	powders and ointments
	moistened towelettes
	pacifiers
	blankets

9.3 Commercial Building Shelter Operations Plan

A shelter designed to the criteria of this manual may be used by a group other than a residential community (e.g., the shelter may have been provided by a commercial business for its workers or by a school for its students). Guidance for preparing a Commercial Building Shelter Operations Plan is presented in this section.

9.3.1 Emergency Assignments

It is important to have personnel assigned to various tasks and responsibilities for emergency situations before they occur. An Emergency Committee, consisting of a Site Emergency Coordinator, a Safety Manager, and an Emergency Security Coordinator (and backups), should be formed, and additional personnel should be assigned to serve on the committee.

The Site Emergency Coordinator's responsibilities include the following:

- maintaining a current Shelter Operations Plan
- overseeing the activation of the Shelter Operations Plan
- providing signage
- notifying local authorities
- implementing emergency procedures
- as necessary, providing for emergency housing and feeding needs of personnel isolated at the site because of an emergency situation
- maintaining a log of events

The Safety Manager's responsibilities include the following:

- ensuring that all personnel are thoroughly familiar with the Shelter Operations Plan
- conducting training programs that include the following, at a minimum:
  - the various warning signals used, what they mean, and what responses are required
  - what to do in an emergency (e.g., where to report)
  - the identification, location, and use of common emergency equipment (e.g., fire extinguishers)
  - shutdown and startup procedures
  - evacuation and sheltering procedures (e.g., routes, locations of safe areas)

- conducting drills and exercises (at a minimum, twice annually) to evaluate the Shelter Operations Plan and to test the capability of the emergency procedures
- ensuring that employees with special needs have been consulted about their specific limitations and then determining how best to provide them with assistance during an emergency (FEMA's United States Fire Administration publication *Emergency Procedures for Employees with Disabilities in Office Occupancies* is an excellent source of information on this topic)
- conducting an evaluation after a drill, exercise, or actual occurrence of an emergency situation, in order to determine the adequacy and effectiveness of the Shelter Operations Plan and the appropriateness of the response by the site emergency personnel

The Emergency Security Coordinator's responsibilities include the following:

- opening the shelter for occupancy
- controlling the movement of people and vehicles at the site and maintaining access lanes for emergency vehicles and personnel
- "locking down" the shelter
- assisting with the care and handling of injured persons
- preventing unauthorized entry into hazardous or secured areas
- assisting with fire suppression, if necessary

The Emergency Committee's responsibilities include the following:

- informing employees in their assigned areas when to shut down work or equipment and evacuate the area
- accounting for all employees in their assigned areas
- turning off all equipment

9.3.2 Emergency Call List

A Shelter Operations Plan for a commercial building should include a list of all current emergency contact numbers. A copy of the list should be kept in the designated shelter area. The following is a suggested list of what agencies/ numbers should be included:

- office emergency management contacts for the building
- local fire department—both emergency and non-emergency numbers
- local police department—both emergency and non-emergency numbers

- local ambulance
- local emergency utilities (e.g., gas, electric, water, telephone)
- emergency contractors (e.g., electrical, mechanical, plumbing, fire alarm and sprinkler service, window replacement, temporary emergency windows, general building repairs)
- any regional office services pertinent to the company or companies occupying the building (e.g., catastrophe preparedness unit, company cars, communications, mail center, maintenance, records management, purchasing/supply, data processing)
- local services (e.g., cleaning, grounds maintenance, waste disposal, vending machines, snow removal, post office, postage equipment, copy machine repair, elevator music supplier)

9.3.3 Tornado/Hurricane Procedures for Safety of Employees

The following procedures should be followed in the event of a tornado or a hurricane:

- The person first aware of the onset of severe weather should notify the switchboard operator or receptionist, or management immediately.
- If the switchboard operator or receptionist is notified, he or she should notify management immediately.
- Radios or televisions should be tuned to a local news or weather station, and the weather conditions should be monitored closely.
- If conditions worsen or otherwise warrant, management should notify the employees to proceed to and assemble in a designated safe area(s). A suggested announcement would be "The area is experiencing severe weather conditions. Please proceed immediately to the designated safe area and stay away from all windows."
- Employees should sit on the floor in the designated safe area(s) and remain there until the Site Emergency Coordinator announces that conditions are safe for returning to work.

9.4 Signage

The Community or Commercial Shelter Management Plan should summarize all activities and strongly encourage community involvement. Area shelter occupants should be given a list of all key personnel and associated contact information. The plan should also describe the type of signage occupants are to follow to reach the shelter. The signs should be illuminated, luminescent, and obvious.

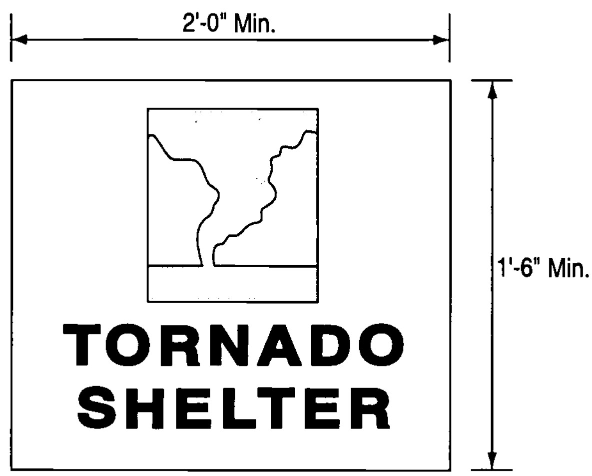
9.4.1 Community Signage

It is very important that shelter occupants can reach the shelter quickly and without chaos. Parking is often a problem at community shelters; therefore, a Community Shelter Operations Plan should instruct occupants to proceed to a shelter on foot if time permits. Main pathways should be determined and laid out for the community. Pathways should be marked to direct users to the shelter. Finally, the exterior of the shelter should have a sign that clearly identifies the building as a shelter.

9.4.2 Building Signage at Schools and Places of Work

Signage for shelters at schools and places of work should be clearly posted and should direct occupants through the building or from building to building. If the shelter is in a government-funded or public-funded facility, a placard should be placed on the outside of the building designating it an emergency shelter (see Figure 9-1). It is recommended that signage be posted on the outside of all other types of shelters as well.

Figure 9-1
Example of a wind shelter sign (see Detail 201, Sheet A2, Schedules and Details, in the plans titled *Community Shelter, Hurricane Floyd Housing Initiative, North Carolina*—see Appendix C of this manual).



SCALE: 3/4" = 1'-0"

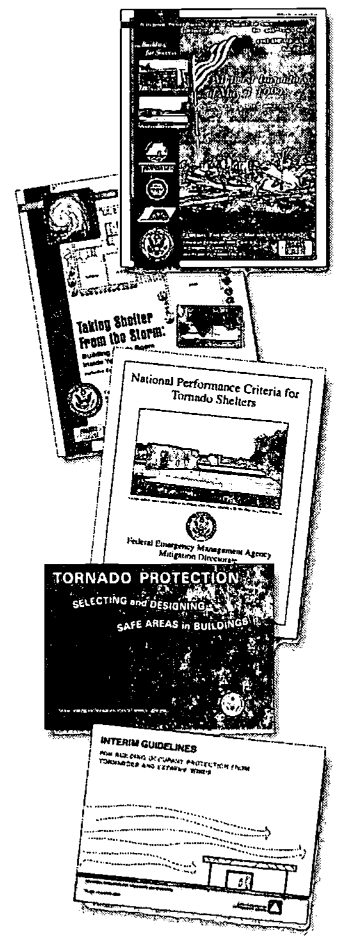
ALUMINUM SIGN BACKGROUND NON-REFLECTIVE. "TORNADO-SHELTER" AND LOGO SHALL BE REFLECTIVE USING 3M SCOTCHLITE DIAMOND GRADE REFLECTIVE SHEETING. YELLOW IN COLOR. VERIFY WITH MANUFACTURER THAT SIGN WILL GLOW FOR A MIN OF 6 HOURS, IN THE EVENT OF POWER LOSS.

It is important to note, however, that once a public building has been identified as a tornado or hurricane shelter, people who live or work in the area around the shelter will expect the shelter to be open during an event. Shelter owners should be aware of this and make it clear that the times when a shelter will be open may be limited. For example, a shelter in an elementary school or commercial building may not be accessible at night.

10 Design Commentary

The design and performance criteria specified in Chapters 5 and 6, respectively, were presented without discussion. This chapter begins with a summary of the existing guidance that has been published on high-wind design. Furthermore, this chapter contains commentary on a number of issues relating to the design and performance criteria and how the criteria should be used with ASCE 7-98 and other codes and standards.

10.1 Previous Publications



In October 1999, FEMA published FEMA 342, *Midwest Tornadoes of May 3, 1999: Observations, Recommendations, and Technical Guidance*. This document presents the observations, conclusions, and recommendations of the BPAT deployed to Oklahoma and Kansas after the May 1999 tornadoes. The conclusions and recommendations are presented to help communities, businesses, and individuals reduce the loss of life, future injuries, and property damage resulting from tornadoes.

In August 1999, FEMA published the second edition of *The National Performance Criteria for Tornado Shelters*. This document presents specific performance criteria for several tornado shelter parameters, including resistance to loads from wind pressure; resistance of walls and ceilings to impacts from windborne missiles; other loads (i.e., adjacent structures); access doors and door frames; ventilation; emergency lighting; sizing; accessibility; emergency management considerations; additional requirements for below grade shelters; multi-hazard mitigation issues; construction plans and specifications; quality control; and obtaining necessary permits.

In August 1999, FEMA also published the second edition of FEMA 320, *Taking Shelter From the Storm: Building a Safe Room Inside Your House*. This document provides homeowners with tools to evaluate the risk of high-wind events at their homes, planning strategies, and construction drawings for in-residence shelters. The construction drawings include plans for in-ground shelters, basement shelters, and aboveground shelters constructed of reinforced concrete, masonry, wood framing, and insulating concrete forms (ICF).

In June 1990, FEMA redistributed FEMA TR-83B, *Tornado Protection: Selecting and Designing Safe Areas in Buildings*. This document provides a review of three schools in the Midwest that were struck by tornadoes in 1974. Effects of high winds are discussed and specific case studies are presented, in addition to guidance for selecting the best available shelter in existing buildings and design parameters for new buildings that would offer protection from high-wind events.

In January 1980, FEMA published FEMA TR-83A, *Interim Guidelines for Building Occupant Protection from Tornadoes and Extreme Winds.* This document provides guidance for the design of high-wind shelters, including the forces generated by extreme winds. The focus is primarily for non-residential construction and includes designs for four hardened rooms (with construction options of reinforced brick masonry, reinforced concrete masonry units, and reinforced concrete). An example of a hardened room design for a school is also presented.

10.2 Commentary on the Design Criteria

The wind load provisions in ASCE 7-98 are based on wind tunnel modeling of buildings considering normal straight-line winds. It is believed that the results from these wind tunnel tests can be used to determine wind pressures from hurricanes. Because the gust structure of straight-line winds of hurricanes compared to tornadoes is believed to be significantly different, the wind tunnel results are not as applicable to tornadoes.

Until more research on the gust structure of tornadoes is conducted, wind engineers must use the same ASCE 7 provisions to calculate wind pressures from tornadoes as they do for other types of high winds. It is imperative that engineers exercise good judgment in the design of a building to resist tornadoes so that actual building performance falls within expected or desired ranges. It is important to note that other effects such as debris impact may control the design of an element rather than the direct wind pressure.

The design methodology presented in this manual is to use the wind load provisions of ASCE 7-98 modified only to the extent that the values of some factors have been specifically recommended because of the extreme nature of tornadic winds. If the values of all coefficients and factors used in determining wind pressures are selected by the user, the results would likely be overly conservative and not representative of the expected building behavior during the tornadic event.

10.2.1 Design Wind Speeds for Tornadoes

Historical data were the key tool used to establish wind speeds and zones associated with areas susceptible to tornado occurrence. The Storm Prediction Center (SPC) archives data for tornadoes, including the time and location of tornado occurrence and the intensity of the tornado.

The National Weather Service assigns an intensity F-scale measurement to each tornado occurrence. The F-scale was developed by Dr. T.T. Fujita in 1971 (Fujita 1971). The intensity F-scale is based on the appearance of damage to buildings and other structures. Dr. Fujita assigned a wind speed range to each F-scale level of damage and ascertained that the ranges represent the fastest 1/4-mile wind speeds. The F-scale and associated fastest 1/4-mile wind speeds are shown in Table 10.1. The table also shows the equivalent 3-second gust speed for each F-scale level. This conversion from fastest 1/4-mile to 3-second gust speed is obtained through the Durst curve given in the commentary of the ASCE 7-98. The wind speed ranges associated with the F-scale, which are based on subjective observation of damage, require some comments.

Table 10.1
Wind Speeds Associated With the Fujita Scale

FUJITA SCALE	FASTEST 1/4-MILE WIND SPEED (mph)*	3-SEC GUST WIND SPEED (mph)**
F0	40 - 72	45 - 77
F1	73 -112	78 - 118
F2	113 - 157	119 - 163
F3	158 - 206	164 - 210
F4	207 - 260	211 - 262
F5	261+	263+

Conversion: 1 mph = 0.447 m/s
* Fujita 1971
** Durst 1960 (ASCE 7-98)

Engineering analyses of damage since 1970 have shown that observed damage to buildings can be caused by wind speeds of less than 200 mph (Mehta 1970, Mehta et al. 1976, Mehta and Carter 1999, Phan and Simiu 1998). Prior to 1970, engineers associated wind speeds above 300 mph with F4 and F5 tornadoes. Although F4 and F5 tornadoes are intense and can cause devastating damage, the wind speeds traditionally assigned to these Fujita categories may well be too high (Minor et al. 1982). There is no evidence that wind speeds in tornadoes at ground level are higher than 200 mph, and certainly not higher than 250 mph. Some research meteorologists also agree with this conclusion. Hence, the wind speed zones are based on the occurrence of intense tornadoes, but the specified wind speeds are not necessarily related to the F-scale.

Data used for the development of wind speed zones are tornado statistics assembled by the NOAA SPC. The statistics used are for the years 1950 through 1998, almost 50 years of data. Tornado occurrence statistics prior to 1950 are available, though they are considered to be of lesser quality. During the 45 years from 1950 to 1994, a total of 35,252 tornadoes were recorded in the contiguous United States. Each of these tornadoes is assigned an F-scale level. The number of tornadoes, percentage in each F-scale level, and cumulative percentages are shown in Table 10.2. As noted in the table, less than 3 percent of the tornadoes are in the F4 category and less than 1 percent of the tornadoes are in the F5 category.

Table 10.2
Tornado Frequencies for the United States (1900-1994)

FUJITA SCALE	NUMBER OF TORNADOES	PERCENTAGE	CUMULATIVE PERCENTAGE
F0	11,046	31.3	31.3
F1	12,947	36.7	68.0
F2	7,717	21.9	89.9
F3	2,523	7.2	97.1
F4	898	2.6	99.7
F5	121	0.3	100
Total	35,252	100	

To develop wind speed zones, the occurrences of tornadoes over the 1950-1998 period are shown in 1-degree longitude-latitude maps. The number of F5 tornado occurrences and combined F4 and F5 tornado occurrences within 1-degree squares were tabulated for the country and used to produce the wind speed map in Figure 2-2. The average area in a 1-degree square is approximately 3,700 square miles. Tornado damage paths are less than 5 square miles on the average; thus, the area covered by a tornado on the ground is quite small compared to the size of a 1-degree square.

A 250-mph wind speed zone has been developed that covers all 1-degree squares that have recorded two or more F5 tornadoes in the last 49 years. This 250-mph zone also includes 10 or more combined F4 and F5 tornado occurrences during the 49 years. In Figure 2-2, the darkest zone covers the middle part of the United States, where the most intense tornado damage has occurred. It also includes large metropolitan areas of the midwestern and southwestern United States (e.g., Chicago, St. Louis, Dallas-Fort Worth). This area with specified wind speeds of 250 mph is designated as Zone IV.

A 200-mph wind speed area, Zone III, is developed using the statistics of F3 tornadoes. F3 tornadoes are less intense and are generally smaller (cover less area on the ground). The number of F3 tornado occurrences in a 1-degree square during the 1950-1998 period were determined for Figure 2-2. Most areas with 20 to 30 F3 tornado occurrences in a 1-degree square are already covered by Zone IV (250 mph wind speed). To be conservative, Zone III, with a wind speed of 200 mph, is extended to cover areas where more than five F3 tornadoes were identified within a single square. This zone extends along the gulf and lower Atlantic coastal areas to include hurricane winds (see Section 10.2.2). There are a couple of 1-degree squares in New York and Massachusetts that fall outside this zone even though they have more than five F3 tornado occurrences. They are considered outliers and have less than 10 F3 occurrences.

A 160-mph wind speed zone is designated as Zone II for the remaining areas east of the Rocky Mountains. The western border for Zone II follows approximately the Continental Divide. The wind speed of 160 mph covers all tornadoes of F2 or lesser intensity and is 75 percent higher than what is specified in ASCE 7-98.

In the areas west of the Rocky Mountains, there are relatively few tornado occurrences, and none have been assigned an intensity scale of F5. Over the past 49 years, only 2 tornadoes were assigned an intensity of F4 and only 10 were assigned an intensity of F3, over the entire region. It is concluded that wind speed of 130 mph is sufficient for this area designated as Zone I. This wind speed is about 50 percent higher than the basic wind speeds specified in ASCE 7-98 for the west coast states.

10.2.2 Design Wind Speeds for Hurricanes

Hurricane intensity is assessed using the Saffir-Simpson Scale of C1 through C5; hurricane category C5 is the most intense and the intensity decreases with the lower categories of storms. There are, on the average, five hurricanes recorded annually in the Atlantic; the landfalling hurricane average is 1.7. The National Hurricane Center of NOAA has archived data on hurricanes since 1900. Hurricane data include track, central barometric pressure, diameter of the eye, distance to hurricane force winds, maximum wind speeds, and storm surge height. The hurricane classification system has a range of wind speeds assigned to each category of storm as shown in Table 10.3.

The wind speeds associated with each category of storm are considered to be 1-minute sustained wind speeds (Powell et al. 1994). These wind speeds are converted to equivalent 3-second gust speeds using Figure C6-1 in the *Commentary* of ASCE 7-98 (Durst 1960). The 3-second gust wind speeds are shown in Table 10.3. The 3-second gust speed permits the development of a unified map for wind speed, as well as use of ASCE 7-98 for determining wind loads. The total number of hurricanes rated category C3, C4, or C5 that struck each U.S. gulf and Atlantic coast state during the period of 1900–1999 (100 years) were also identified and included in the preparation of Figure 2-2. The data show that no hurricanes of intensity C4 and C5 have made landfall north of the North Carolina coast. Also, during the last 100 years, only two category C5 storms have made landfall—an unnamed hurricane struck Florida in 1935 and Hurricane Camille made landfall in Mississippi and Louisiana in 1969. Based on those historical data, two wind speed zones are established for hurricane-prone coastal areas.

Table 10.3
Saffir-Simpson Hurricane Scale

SAFFIR-SIMPSON SCALE	1-MIN SUSTAINED WIND SPEED (mph) *	3-SEC GUST WIND SPEED (mph) **
C1	74 - 95	90 - 116
C2	96 - 110	117 - 134
C3	111 - 130	135 - 159
C4	131 - 154	160 - 188
C5	155 +	189+

Conversion: 1 mph = 0.447 m/s
* Powell 1993
** Durst 1960 (ASCE 7-98)

A design wind speed of 160-mph is specified for coastal areas north of North Carolina. This wind speed covers hurricane category C3 and less intense storms. It is assumed that hurricane winds affect areas up to 100 miles inland from the coastline. Zone II developed for tornadic winds matches this hurricane wind speed zone.

Along the gulf coast and the lower Atlantic coastal states (including North Carolina), a design wind speed of 200 mph is specified. This design wind speed matches the wind speed of Zone III established for tornadic winds. Hurricane winds are assumed to reach 100 miles inland from the coastline. Establishment of these wind speeds for hurricanes provides a unified map for design wind speeds for shelters in the 48 contiguous states.

For the islands of Hawaii and other territories, which are affected by hurricanes, design wind speeds are specified based on wind speed values in ASCE 7-98. The Territory of Guam uses a wind speed of 170 mph for normal design (ASCE 7-98). For shelter designs in Guam, the wind speed specified is 250 mph, the same as Zone IV. For other island areas where wind speeds specified in ASCE 7-98 range from 125 to 145 mph, a design wind speed of 200 mph is recommended for shelters, the same as in Zone III. For the islands of Hawaii, where the design wind speed specified in ASCE 7-98 is 105 mph, a design wind speed of 160 mph is recommended for shelters. This specification of wind speeds simplifies the use of the wind speed map and provides a reasonable factor of safety.

10.2.3 Wind Speeds for Alaska

The state of Alaska does not experience hurricanes and is not prone to a significant number of tornadoes. It does experience extratropical cyclone winds and thunderstorms. Since there are no specific records of extreme storms in Alaska, the shelter design wind speeds are based on contours shown on the map in ASCE 7-98. It is recommended that wind speeds for Zone II (160 mph) be used for areas that show ASCE 7-98 wind speeds of 110 mph or higher. For the interior areas where ASCE 7-98 wind speeds are less than 110 mph, the shelter design wind speed of Zone I (130 mph) is recommended.

10.2.4 Probability of Exceeding Wind Speed

Wind speeds specified on the map are obtained from available historical storm data, delineated wind speed contours from ASCE 7-98, and subjective judgment. The wind speed contours in ASCE 7-98 were obtained by dividing 500-year hurricane wind speed contours by "effective load factors" that are based on wind event return periods (ASCE 7-98, Section 66.5.4). This results in design-level wind speed contours that incorporate an implied importance factor for hurricane-prone areas. The implied importance factor ranges from near 1.0 up to about 1.25 (the explicit value in ASCE 7-93 is 1.05). ASCE 7-98 requires the use of an importance factor of 1.15 on loads if a building function is needed for post-storm operation or collapse of the structure is detrimental to a large number of people.

In addition, ASCE 7-98 wind speeds and loads are associated with allowable stress design. Additional safety against collapse is provided through the use of allowable stress in design or through load factors for limit state design. It is judged that the shelter design wind speeds and load combinations of ASCE 7-98 are associated with a 0.002 to 0.001 annual probability of severe damage or collapse (500- to 1,000-year mean recurrence interval [MRI]).

Community shelter designs should be based on wind speeds for low-probability events. The annual probability of exceeding the wind speed specified in the map varies widely because probabilities are based on historical data and subjective judgment. This is acceptable since data of storms also vary widely.

In the areas west of the Rocky Mountains and in Alaska, there are very few extreme storms, if any. In this area, the shelter design wind speeds will have a probability of exceedance of about 0.00033 (3,000-year MRI).

For hurricane regions, the annual probability of exceedance of wind speeds may be in the range of 0.0005 to 0.0001 (2,000- to 10,000-year MRI). For example, the Southern Florida region wind speed of 200 mph is associated with an annual probability of exceedance of 0.005 (2,000-year MRI), as obtained from the Monte Carlo numerical simulation procedure (Batts et al. 1980).

For tornadic regions, the annual probability of exceedance of wind speeds may be in the range of 5×10^{-5} to 1×10^{-6} (20,000- to 1,000,000-year MRI). For example, the Kentucky region wind speed of 250 mph is associated with an annual probability of exceedance of 1×10^{-6} (1,000,000-year MRI) (Coats and Murray 1985). This low probability of exceedance of wind speed in Zone IV is acceptable because the data used to calculate probability are of low quality.

It may be appropriate for a designer to develop a wind hazard model to obtain wind speeds associated with some low probability of exceedance for design purposes. Designers are cautioned that the quality of data along with appropriate statistical method should be taken into consideration to obtain the hazard model.

10.3 Commentary on the Performance Criteria

Windborne debris and falling objects are two of the risks that shelters are designed to mitigate against. Windborne debris and falling objects can be described in terms of their mass, shape, impact velocity, angle of impact, and motion at impact (i.e., linear motion or tumbling). The mass and impact velocity can be used to calculate a simple upper bound on the impact momentum and impact energy by assuming linear motion of the debris striking perpendicular to the surface. In this instance, the impact momentum is calculated using Formula 10.1, where W is the weight of the debris, g is the acceleration of gravity, and V is the impact velocity. For similar conditions, the impact energy can be calculated from Formula 10.2. I_m and I_e are the impact momentum and impact energy, respectively, for simple linear impacts perpendicular to the surface.

These equations provide reasonable estimates of impact momentum and impact energy for compact debris, where the length-to-diameter ratio is less than about 2, striking perpendicular to the surface. They also provide reasonable estimates for slender rigid body missiles striking on end, perpendicular to the surface when there is very little rotation of the missile. For off-angle impacts of compact debris (impacts at some angle to the surface), the normal component of the impact momentum and impact energy can be estimated with Formulas 10.1 and 10.2 if the velocity V is replaced by an effective velocity V′. Where $V' = V \cos(\Theta)$ and the angle Θ is measured relative to the axis normal to the surface.

Formula 10.1 Impact Momentum

$$I_m = (W/g)(V)$$

where: I_m = impact momentum
W = weight of debris
g = acceleration of gravity
V = impact velocity

Formula
Impact Momentum

Formula 10.2 Impact Energy

$$I_e = (1/2)(W/g)(V^2)$$

where: I_e = impact energy
W = weight of debris
g = acceleration of gravity
V = impact velocity

Formula
Impact Energy

For slender, rigid-body missiles such as wood structural members, pipes or rods, where the length-to-diameter ratio is greater than about 4, the angle of impact and the motion characteristics at impact become very important. Research has shown that the normal component of the impact drops off more rapidly than a simple cosine function for linear impact of long objects because the missile begins to rotate at impact (Pietras 1997). Figure 10-1, based on data from Pietras 1997, shows the reduction in normal force as a function of angle as compared to a cosine function reduction. For tumbling missiles, the equivalent impact velocity has been estimated using a complex equation (Twisdale and Dunn 1981, Twisdale 1985).

The impact of windborne debris can apply extremely large forces to the structure and its components over a very short period of time. The magnitude of the force is related to the mass of the object and the time of the deceleration as the missile impacts a surface of the shelter. The magnitudes of the forces also depend on the mechanics involved in the collision. For example, inelastic crushing of the wall or the missile will absorb some of the impact energy and reduce the force level applied to the structure. Similarly, large elastic or inelastic deformation of the structure in response to the impact can increase the duration of the deceleration period and hence reduce the magnitude of the impact forces. For a perfectly elastic impact, the impulse force exerted on the structure is equal to twice the impact momentum since the missile rebounds with a speed of equal magnitude to the impact velocity but in the opposite direction. For a perfectly plastic impact, the missile would not rebound and the impulse force would be equal to the impact momentum.

Figure 10-1
Variations of impact impulse as a function of impact angle.

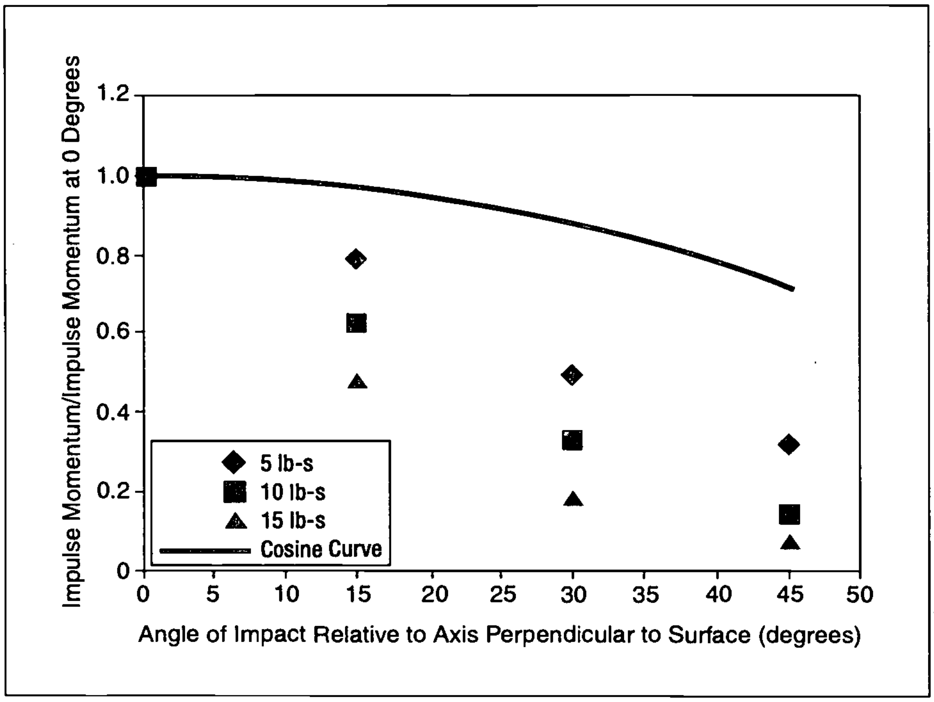


Figure 10-2 illustrates the impulse loading applied by a 4.1-lb Southern Yellow Pine 2x4 (nominal) missile striking a rigid impact plate at a velocity of 42.3 fps (21 mph). Note that the entire impulse force is applied over a period of 1.5 milliseconds and the peak force approaches 10,000 lb. Similar tests with a 9-lb wood 2x4 at 50 fps (34 mph) generated peak forces of around 25,000 lb. The dotted (raw) line represents the measured impulse force and includes some high-frequency response of the impact plate. The signal has been "filtered" to remove the high-frequency response of the impact plate and illustrate the expected impulse forces time history.

Impact test results for Southern Yellow Pine 2x4 members of various mass striking the impact plate at different velocities illustrate the complex nature of the impact phenomenon (Sciaudone 1996). Figure 10-3 compares the impulse force measured with the impact plate against the initial momentum of the missile. At low velocities, the impulse is characteristic of an inelastic impact where the impulse is equal to the initial momentum. This is likely due to the localized crushing of the wood fibers at the end of the missile. As the missile speed increases (initial momentum increases), the impulse increases toward a more elastic impact response because the impulse force increases to a value, which is substantially greater than initial momentum.

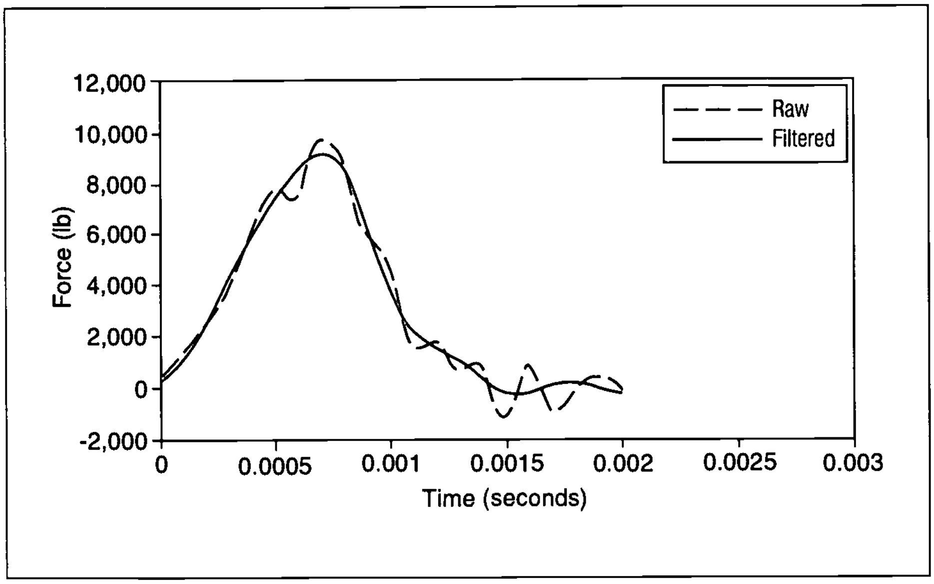


Figure 10-2
Raw and filtered forcing functions measured using impact plate for impact from a 4.1-lb 2x4 moving at 42.3 fps (Sciaudone 1996).

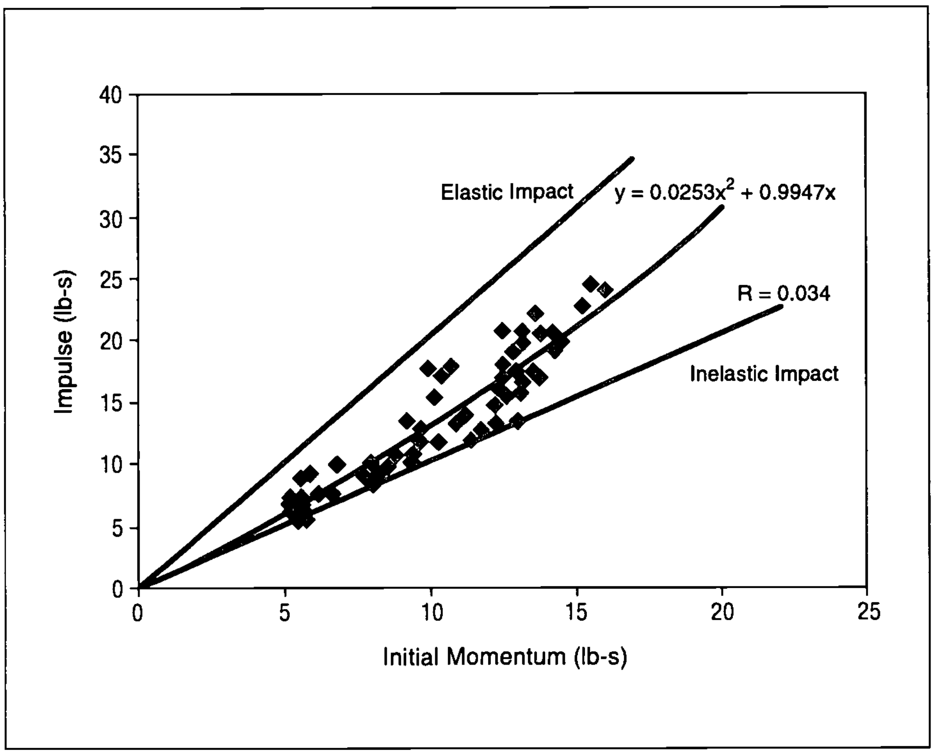


Figure 10-3
Impulse as a function of initial missile momentum for 2x4.

Design considerations should include local failures associated with missile perforation or penetration, as well as global structural failure. Sections 6.2.3 through 6.2.7 of this manual provide discussions that center on local failures. Global failures are usually related to overall wind loading of the structure or the very rare impact of an extremely large missile. Falling debris such as elevated mechanical equipment could cause a buckling failure of a roof structure if it impacted near the middle of the roof.

11 References

American Concrete Institute. 1999. *Building Code Requirements for Structural Concrete and Commentary*. ACI 318-99 and ACI 318R-99. Farmington Hills, MI.

American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures*, ASCE 7-98 Public Ballot Copy, American Society of Civil Engineers. Reston, VA.

ANSI/AF&PA NDS-1997. 1997. *National Design Specification for Wood Construction*. August.

Batts, M.E., Cordes, M.R., Russell, L.R., Shaver, J.R. and Simiu, E. 1980. *Hurricane Wind Speeds in the United States*. NBS Building Science Series 124. National Bureau of Standards, Washington, DC. pp. 41.

Carter, R. R. 1998. *Wind-Generated Missile Impact on Composite Wall Systems*. MS Thesis. Department of Civil Engineering, Texas Tech University, Lubbock, TX. May.

Clemson University Department of Civil Engineering. 2000. *Enhanced Protection from Severe Wind Storms*. Clemson University, Clemson, SC. January.

Coats, D. W., and Murray, R. C. 1985. *Natural Phenomena Hazards Modeling Project: Extreme Wind/Tornado Hazard Models for Department of Energy Sites*. UCRL-53526. Rev. 1. Lawrence Livermore National Laboratory, University of California, Livermore, CA. August.

Durst, C.S. 1960. "Wind Speeds Over Short Periods of Time," *Meteorology Magazine*, 89. pp.181-187.

Federal Emergency Management Agency. 1976. *Tornado Protection: Selecting and Designing Safe Areas in Buildings*. TR-83B. April.

Federal Emergency Management Agency. 1980. *Interim Guidelines for Building Occupant Protection From Tornadoes and Extreme Winds*. TR-83A. September.

Federal Emergency Management Agency. 1988. *Rapid Visual Screening of Building for Potential Seismic Hazards: A Handbook.* FEMA 154 Earthquake Hazards Reduction Series 41. July.

Federal Emergency Management Agency. 1997. *NEHRP Recommended Provisions for Seismic Regulations for New Buildings.* FEMA 302A.

Federal Emergency Management Agency. 1999a. *Midwest Tornadoes of May 3, 1999: Observations, Recommendations, and Technical Guidance.* FEMA 342. October.

Federal Emergency Management Agency. 1999b. *National Performance Criteria for Tornado Shelters.* May 28.

Federal Emergency Management Agency. 1999c. *Taking Shelter From the Storm: Building a Safe Room Inside Your House.* FEMA 320. Second Edition. August.

Federal Emergency Management Agency and U.S. Fire Administration. Undated. *Emergency Procedures for Employees with Disabilities in Office Occupancies.*

Fujita, T.T. 1971. *Proposed Characterization of Tornadoes and Hurricanes by Area and Intensity.* SMRP No. 91. University of Chicago, Chicago, IL.

HQ AFCESA/CES. *Structural Evaluation of Existing Buildings for Seismic and Wind Loads.* Engineering Technical Letter (ETL) 97-10.

Kelly, D.L., J.T. Schaefer, R.P. McNulty, C.A. Doswell III, and R.F. Abbey, Jr. 1978. " An Augmented Tornado Climatology." *Monthly Weather Review*, Vol. 106, pp. 1172-1183.

Krayer, W.R. and Marshall, R.D. 1992. *Gust Factors Applied to Hurricane Winds.* Bulletin of the American Meteorology Society, Vol. 73, pp. 613-617.

Masonry Standards Joint Committee. 1999. *Building Code Requirements for Masonry Structures* and *Specification for Masonry Structures.* ACI 530-99/ ASCE 5-99/TMS 402-99 and ACI 530.1/ASCE 6-99/TMS 602-99.

Mehta, K.C. 1970. "Windspeed Estimates: Engineering Analyses." *Proceedings of the Symposium on Tornadoes: Assessment of Knowledge and Implications for Man.* 22-24 June 1970, Lubbock, TX. pp. 89-103.

Mehta, K.C., and Carter, R.R. 1999. "Assessment of Tornado Wind Speed From Damage to Jefferson County, Alabama." *Wind Engineering into the 21st Century: Proceedings, 10th International Conference on Wind Engineering*, A. Larsen, G.L. Larose, and F.M. Livesey, Eds. Copenhagen, Denmark. June 21-24. pp. 265-271.

Mehta, K.C., Minor, J.E., and McDonald, J.R. 1976. "Wind Speed Analysis of April 3-4, 1974 Tornadoes." *Journal of the Structural Division, ASCE*, 102(ST9). pp. 1709-1724.

Minor, J.E., McDonald, J.R., and Peterson, R.E. 1982. "Analysis of Near-Ground Windfields." *Proceedings of the Twelfth Conference on Severe Local Storms* (San Antonio, Texas, 11-15 January 1982). American Meteorological Society, Boston, MA.

National Concrete Masonry Association. 1972. *Design of Concrete Masonry Warehouse Walls*. TEK 37. Herndon, VA.

O'Neil, S., and Pinelli, J.P. 1998. *Recommendations for the Mitigation of Tornado Induced Damages on Masonry Structures*. Report No. 1998-1. Wind & Hurricane Impact Research Laboratory, Florida Institute of Technology. December.

Phan, L.T., and Simiu, E. 1998. *The Fujita Tornado Intensity Scale: A Critique Based on Observations of the Jarrell Tornado of May 27, 1997*. NIST Technical Note 1426. U.S. Department of Commerce Technology Administration, National Institute of Standards and Technology, Washington, DC. July.

Pietras, B. K. 1997. "Analysis of Angular Wind Borne Debris Impact Loads." Senior Independent Study Report. Department of Civil Engineering, Clemson University, Clemson, SC. May.

Powell, M.D. 1993. *Wind Measurement and Archival Under the Automated Surface Observing System (ASOS)*. Bulletin of American Meteorological Society, Vol. 74, 615-623.

Powell, M.D., Houston, S.H., and Reinhold, T.A. 1994. "Standardizing Wind Measurements for Documentation of Surface Wind Fields in Hurricane Andrew." *Proceedings of the Symposium: Hurricanes of 1992* (Miami, Florida, December 1-3, 1993). ASCE, New York. pp. 52-69.

Sciaudone, J.C. 1996. *Analysis of Wind Borne Debris Impact Loads*. MS Thesis. Department of Civil Engineering, Clemson University, Clemson, SC, August.

Steel Joist Institute. *Steel Joist Institute 60-Year Manual 1928-1988.*

Texas Tech University Wind Engineering Research Center. 1998. *Design of Residential Shelters From Extreme Winds*. Texas Tech University, Lubbock, TX. July.

Twisdale, L.A., and Dunn, W.L. 1981. *Tornado Missile Simulation and Design Methodology*. EPRI NP-2005 (Volumes I and II). Technical Report. Electric Power Research Institute, Palo Alto, CA. August.

Twisdale, L.A. 1985. "Analysis of Random Impact Loading Conditions." *Proceedings of the Second Symposium on The Interaction of Non-Nuclear Munitions with Structures*. Panama City Beach, FL. April 15-18.

U.S. Department of Energy. 1994. *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*. DOE-STD-1020-94. Washington, DC. April.

Appendix A
Benefit/Cost Analysis Model for Tornado and Hurricane Shelters

Decisions regarding the effectiveness of hazard mitigation projects are often based on the cost-effectiveness of those projects. Evaluating the benefits of protecting against tornadoes and hurricanes involves a complex series of probability computations. To facilitate the analyses, FEMA developed a software application to calculate the benefit-cost (B/C) ratio of tornado and hurricane community shelters. The software can be found on the CD-ROM included in this appendix. The CD-ROM also includes a detailed User's Guide that contains instructions for installing the B/C model software and conducting sample runs. The User's Guide is provided in the form of a Portable Document Format (PDF) file that can be read and printed with the Adobe Acrobat® Reader, which is also provided on the CD-ROM.

A.1 Hardware and Software Requirements

The Benefit-Cost Analysis Model for Tornado and Hurricane Shelters is a stand-alone software application. The application requires the following:

- IBM-compatible computer (PC) with Pentium® 90MHz or higher microprocessor.
- VGA 1024 (768 or higher resolution screen supported by Microsoft Windows®.
- 24MB RAM for Windows 95®, 32MB for Windows NT® and Windows 98®.
- Hard drive with at least 40 MB of free disk space.
- CD-ROM drive
- Microsoft Windows 95® or later or Microsoft Windows NT® 3.51 or later
- Adobe Acrobat® Reader 3.0 or later (Adobe Acrobat® Reader 4.0 is included on the CD-ROM.)

A.2 Software Installation

It is recommended to close all other applications before installing the software. For Windows NT® users, be sure you have software installation privileges for your computer or have your system administrator install the software.

1. From Windows, run Setup.exe from the CD-ROM. One way to do this is to use Window Explorer® to navigate to the CD-ROM drive and double-clicking on the Setup.exe file. Also, the Run command under the Start button can be used to type d:\Setup.exe, where d: should be substituted by the actual letter for the CD-ROM drive.

2. The setup program will initially copy some temporary files. After this step has been completed, you will be prompted to start the software installation by clicking on the OK button. You can also cancel the installation program by clicking on the Exit button.

3. If you clicked OK, the next screen will contain the options to Exit, to change the installation directory, and to install the software to the specified directory.

4. By clicking the Change Directory button, you will have the option to change the directory where the software will be installed. The selected hard drive must have at least 40 MB of free space.

5. After the installation directory has been set, click the button with the computer and disk graphic to start the software installation. The installation software will then copy the required files to the specified installation directory and the Windows® system directory, and will update the registry.

6. During the installation process, you may be prompted about whether to overwrite an existing file with a new file from the installation program. The typical situation when this message is displayed is when the setup program detects a ".dll" file with the same name as the one about to be installed. In many cases, the file being written by the installation program is a more recent version of the dll in the computer and could replace the existing file. If you are unsure, you may skip overwriting the file; however, there is a chance that the benefit-cost software may not operate properly.

7. After all of the files have been copied and the registry updated, the installation program will display a window that indicates that the software installed correctly. Click the OK button and the installation program will close. Before running the model for the first time, be sure to restart your computer.

8. As part of the installation process, a new item, "Tornado and Hurricane Shelter Mitigation," will be added to the Windows® taskbar Start button Programs menu. Selecting this item from the menu will display a rollover

list that will give you access to the Benefit Cost Model, the Benefit Cost Model Help feature, the User's Guide (in PDF format), and a copy of the Evaluation Checklist from Appendix B (also in PDF format). If you would like to create a shortcut to the model on your desktop, right-click on Benefit Cost Model in the rollover list, drag the icon to your desktop, release the mouse button, and choose Create Shortcut Here from the displayed menu.

A.3. Uninstalling the Software

The install program automatically creates an uninstall procedure for the software. It will delete all files and directories created by the install program.

1. Under the Windows® taskbar Start button, select Settings and then Control Panel.
2. In the Control Panel window, double-click the Add/Remove Programs icon.
3. In the Add/Remove Programs window, on the Install/Uninstall tab, select Tornado and Hurricane Shelter Mitigation from the displayed list, and click the Add/Remove button.
4. The uninstall procedure will remove all files and directories installed by the install program. It will also remove Tornado and Hurricane Shelter Mitigation from the Programs menu. You may be prompted about removing shared files. Usually you do not uninstall shared files, since other programs may require those files. You may also be notified if there is a problem deleting certain files or directories.
5. A window will indicate when the software has been completely uninstalled.

Appendix B
Site Assessment Checklists

Overview

FEMA has developed checklists for evaluating and compiling data about tornado refuge areas. This work was performed for FEMA by the engineering consulting firm of Greenhorne & O'Mara, Inc., under the Hazard Mitigation Technical Assistance Program. The checklists can be used to evaluate existing refuge areas or to select potential new refuge areas within buildings in tornado-prone areas as well as areas subject to high-wind events such as hurricanes. Prudent engineering guidelines were used in the development of the checklists. Therefore, using the checklists and reviewing design or construction plans in the absence of engineering analysis allows for a reasonable assessment of the vulnerability of potential refuge areas.

The objectives of the checklists are twofold: (1) to identify structural and non-structural vulnerabilities to tornado events, and (2) to rank a group of facilities to determine which have the least structural resistance to high wind forces and are in greatest need of retrofitting solutions.

The checklists are divided into five sections; the evaluation process is based on a multi-hazard approach with an emphasis on the wind hazard:

- General Building Information
- Selecting the Refuge Area
- Wind Hazard Checklist
- Flood Hazard Checklist
- Structural Seismic Hazard Checklist

In the *General Building Information* section, data pertaining to the building site are gathered, including site name, address, point of contact, and historical information about building performance, maintenance problems, and repairs. Other data collected for this section include population, building size and shape, power sources, and an assessment of the surrounding environment and general condition of the building.

In the section titled *Selecting the Refuge Area*, the user is guided through a preliminary process to identify potential refuge areas, eliminating areas that are more vulnerable to wind events and focusing on those that provide more protection. Several areas may be needed to accommodate all occupants. If refuge areas have not been identified by the building occupants, the designer/evaluator will need to calculate the refuge space requirement at the site. Thus, the first step in selecting the refuge area is to calculate the space needed for the maximum possible number of occupants (e.g., students, staff) at any given time. The next step is to look for available space, noting accessibility and potential vulnerabilities.

Once the refuge areas have been identified, the screening is focused on those areas. The hazard checklists consist of detailed questions about structural, cladding and glazing, envelope protection, and non-structural issues. Penalty points are assigned to answers that indicate inadequate building strength or unfavorable circumstances under hazard conditions. The checklists are used to gather information that provides a "big picture" and allows a thorough analysis to be conducted. Scores on the checklists will highlight specific deficiencies and provide the means of ranking a group of facilities. The scores will identify refuge areas that are candidates for retrofit designs as well as those that are poor candidates because of excessive vulnerabilities.

The wind hazard checklist is divided into four sections in which information is gathered related to common failure modes that occur under the effects of tornadoes. The four sections are as follows:

- Structural Issues – Building materials used for framing and critical components are identified. The existence of a continuous load path is determined, and the overall structural resistance of the building is assessed.
- Cladding and Glazing Issues – Non-structural components that are often vulnerable to missile impact and high wind pressures are identified (e.g., windows and roof coverings).
- Envelope Protection – Refuge walls and roof coverings are evaluated for their susceptibility to a breach by either missile impact or high wind pressures. When the building envelope is breached, additional wind pressures are imposed on interior surfaces.
- Non-structural Issues – Issues related to the adequacy of a refuge area that do not concern building performance are evaluated (e.g., ADA accessibility, availability and sufficiency of a backup power source, and having an evacuation plan in place prior to a severe event).

Flood and seismic hazard checklists are included to ensure that the building is not vulnerable to multi-hazards. If a multi-hazard vulnerability exists, a mitigation strategy must be developed that responds to all possible threats. The flood hazard checklist relies on information obtained from a National Flood Insurance Program (NFIP) Flood Insurance Rate Map (FIRM)—a map that shows 100-year flood hazard areas and 100-year flood elevations within a community. This section also examines localized flooding and drainage problems that may exist outside the identified floodplain. The seismic checklist uses the 1997 Uniform Building Code Seismic Zone Map of the United States and guidelines from FEMA 154, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*, from the *Earthquake Hazards Reduction Series*. These two references are used to outline a simplified procedure for the seismic evaluation. If seismic calculations are required for the refuge in question, the designer is advised to use the seismic sections of the 2000 IBC or the guidance presented in FEMA 273, *NEHRP Guidelines for the Seismic Rehabilitation of Buildings*.

EVALUATION CHECKLISTS FOR HIGH-WIND REFUGE AREAS

Wind hazard evaluation checklists were developed by FEMA for use in assessing a building's susceptibility to damage from high wind events such as tornadoes. The checklist evaluation process will guide the user in identifying potential refuge areas at a site with 1 or more buildings. If the refuge area selected is to be considered for use as a "shelter," it should be structurally independent, easily accessible, and contain the required square footage. Most importantly, the refuge area should be resistant to wind forces or made more resistant with mitigation retrofits.

An inspector can use the checklists to assess the ability of the refuge area to resist forces generated by a tornadic event. These checklists were designed for the evaluation of tornado refuge areas but may also be used to evaluate refuge areas for other high-wind events, such as hurricanes. The checklists consist of questions pertaining to structural and non-structural characteristics of a facility. The questions are designed to identify structural and non-structural vulnerabilities to wind hazards based on typical failure mechanisms. Structural or non-structural deficiencies may be remedied with retrofit designs, but, depending on the type and degree of deficiency, the evaluation may indicate that the structure is unsuitable as a refuge area. The checklists are not a substitute for a detailed engineering analysis, but can assist the decision-makers involved with hazard mitigation and emergency management to determine which areas of buildings can best serve as refuge areas.

The checklists can also be used to comparatively rank a group of facilities within a given geographic region. A scoring system was developed for use with the checklists. For each question on the checklist, penalty points are associated with noted deficiencies. Therefore, a high score reflects higher hazard vulnerability and a low score reflects higher hazard resistance, but only relative to the other buildings considered in the scoring system. This evaluation process helps determine which building will perform best under natural hazard conditions in the least subjective manner possible. The checklists help identify the areas within buildings that are least vulnerable to damage from high winds and will likely require the least mitigation to achieve near-absolute protection.

Five sections are provided: General Building Information, Selecting the Refuge Area, Wind Hazard Checklist, Flood Hazard Checklist, and Structural Seismic Hazard Checklist. A summary score sheet has been provided with the evaluation checklists to compile the evaluation scores for each natural hazard. A description of common building types and a glossary of terms are presented following the checklists.

CHECKLIST INSTRUCTIONS

The checklists are designed to walk the user through a step by step process and should be filled out in sequence. This process is a rapid visual screening and does not involve any destructive testing or detailed engineering calculations. A large portion of the checklists can be filled out using data obtained from design or construction plans. It is important to verify this data during a field inspection and note upgrades (i.e., expect roof replacements on older buildings). If building plans are not available for this evaluation, the accuracy of the checklists is compromised. Additional information can be acquired from building specifications, site visits, and interviews with building maintenance personnel who can provide historical information on specific problems, repairs, upgrades, and school procedures.

General Building Information: This section is for collecting information for reference purposes. All questions relate to the entire building or buildings at the site. The user may need to refer back to the General Building Information section to answer hazard related questions in other sections. This section is not scored.

Selecting the Refuge Area: The focus of the evaluation is to select appropriate refuge areas that might provide protection from high wind and tornadic events. The criteria contained in this section will guide the user on how to select good candidate refuge areas. Several refuge areas may be needed to provide enough usable space for the entire population in need of protection. A separate checklist should be filled out for each potential refuge area. This section is not scored.

Wind Hazard Checklist: This checklist applies only to the refuge area(s). If more than one area is selected, a separate checklist should be filled out for each area. A glossary with diagrams is provided (starting on page 26) to help the user with unfamiliar terminology. Answer the questions and determine a score for this hazard.

Flood Hazard Checklist: This section applies to both the refuge area and to the entire building. A Flood Insurance Rate Map (FIRM) is required to answer most of the questions in this section. Answer the questions and determine a score for this hazard.

Structural Seismic Hazard Checklist: The checklist for the seismic threat pertains to the entire building. A Seismic Activity Zone Map is provided to help assess the seismic threat. Answer the questions and determine a score for this hazard.

Summary Score Sheet: After answering and scoring all of the questions in the checklists, the Summary Score Sheet should be filled out. The score sheet is used to compile all of the scores for each refuge area associated with each site for comparison. The total scores will enable the user to rank each building and its potential as an adequate refuge area.

Transfer checklist scores to the Summary Score Sheet to include subscores from the wind section for each refuge area evaluated. The highest Area Total Wind Hazard Score should be placed in the Highest Wind Hazard Score block. The Total Score is the sum of the Highest Wind Hazard Score, Flood Hazard Score, and Seismic Hazard Score. The Total Scores will reflect the expected performance ranking of the buildings when placed in order from lowest to highest score, (i.e., least vulnerable to most vulnerable structure).

Low scores on the checklists indicate structural features that provide some level of protection. Higher scores indicate that a refuge area is more vulnerable to wind damage. The lowest possible cumulative score for Zone 4 (region most vulnerable to tornado hazards) is 20 and a refuge area with this score would likely provide significant protection from a high-wind event; however, it is very unlikely that any building, even one with an engineered storm shelter, would have this score. For example, a pilot study of 10 schools in Wichita (located in Zone 4) resulted in scores ranging from 56 to 161.

General Building Information

CONTACT INFORMATION

Site Name: ______

Street Address: ______

City, State, Zip: ______

Contact Person : ______

Contact Phone #: ______

Total population: ______

Typical hours the building is occupied: ______

Is the building locked at any time? ______

BUILDING DATA

Size/Square Footage: ______ Number of Stories: ______

Describe the building configuration: ______

General description of surrounding area: ______

Are there any portable/temporary units: ______ How many: ______

Describe the condition of the building (are there cracks in the walls, signs of deterioration, rusting, peeling paint, or other repair needs):

What are the power or fuel sources for the following utilities (natural gas, oil, electric, LP, etc.)? ______

☐ Heating: ______ ☐ Cooling: ______ ☐ Cooking: ______

Is there a refuge area or shelter already identified within the building? ______

Was this shelter designed for high winds? (indicate the design professional and all relevant design parameters, specifically design wind speed): ______

Evaluator's Name: ______ Date of Evaluation: ______

Site Name: ______

Provide a general sketch of the building

Additional Comments:

Evaluator's Name: ______________________ Date of Evaluation: ______________

Site Name: ______________________

SELECTING THE REFUGE AREA

What are all the potential areas in the building that provide adequate space for the entire population during a high-wind event?
(For Tornado Use, Required Square Footage [RSF] = Total Population x 5 square feet)
(For Hurricane Use, RSF = Total Polulation x 10 square feet)

____

Which areas should be eliminated because of excessive glazing (greater than 6% windows) and/or long unsupported wall and roof spans (greater than 40 feet)? _______________

Which areas should be eliminated because of potential damage from nearby heavy collapsed structures (e.g., concrete towers, telephone poles, chimneys)? _______________

Of remaining candidates, how accessible is the refuge area to all building occupants, including the disabled? _______________

If refuge area is cluttered, can materials be easily moved to create additional usable space? _______________

How much usable space exists? Is USF≥RSF [USF = ASF x 0.85]? _______________
Required Squared Footage = RSF   Available Square Footage = ASF   Usable Square Footage = USF
[Note: when bathrooms are used, USF = ASF x 0.50] _______________

On basis of information above, choose best refuge areas (interior spaces provide best protection). Explain choice and rank them from most desirable to least desirable. _______________

Evaluator's Name: _______________ Date of Evaluation: _______________

Site Name: _______________

Sketch refuge areas within building layout and show access routes (an existing floorplan may be marked up and attached in lieu of the sketch):

Additional Comments:

Evaluator's Name: ____________________ Date of Evaluation: ____________

Site Name: ____________________

WIND HAZARD CHECKLIST

Address the following evaluation statements, giving the most appropriate answer for each question. After selecting the appropriate answer, take the score for that answer (# in the parentheses) and enter it into the score block for that question. Evaluation judgment is subject to limitations of visual examination. Questions have been grouped into sections based on structural issues, cladding and glazing, envelope protection, and non-structural issues. These questions apply only to the refuge area. **After all questions have been appropriately scored, sum the score column and determine the final wind hazard score for the refuge area.**

QUESTION	SCORE
STRUCTURAL ISSUES	
Refuge Area Size Length: ______ Width: ______ Height: ______ Stories: ______	**NO SCORE**
Usable square footage for this area:	**NO SCORE**
When was building constructed? Check box below. ☐ 1995 or newer (0) ☐ 1994 - 1988 (2) ☐ 1987 - 1980 (4) ☐ 1979 - 1970 (6) ☐ 1969 - 1951 (8) ☐ Pre - 1950 (10) **Date on plans:**	
The building was designed according to the following building code: ☐ Uniform Building Code, Year: ☐ International Residential Code: Year: ☐ Standard Building Code, Year: ☐ International Building Code, Year: ☐ National Building Code, Year: ☐ Other Code:	**NO SCORE**
What is the structural construction material of the refuge area? ☐ Concrete (10) ☐ Pre-Cast Concrete (10) ☐ RM (10) ☐ Engineered/Heavy Steel Frame (12) ☐ PRM (15) ☐ URM (20) ☐ Wood or Metal Studs (20) ☐ Light Steel Building/Pre-engineered (20) ☐ Unknown (20)	

Evaluator's Name: ______________________ Date of Evaluation: ____________

Site Name: ______________________

What building plans are available for the inspection?

- ☐ As-built Plans (including full architectural and structural plans (0)
- ☐ Design/Construction Plans (including full architectural and structural plans) (2)
- ☐ Structural Plans only (3)
- ☐ Architectural Plans only (5)
- ☐ Partial set of plans (8)
- ☐ No plans are available (12)

Vertical and Lateral Load Resisting Systems (select the system that applies)

☐ Moment Resisting Frame (identify infill wall below) (0)

- ☐ Concrete Beams/Columns
- ☐ Precast Concrete Beams/Columns
- ☐ Steel Beams/Columns
- ☐ Wood Beams/Columns
- ☐ Steel Bar Joist and Concrete or Masonry Columns

☐ Infill Wall of Moment Resisting Frame (identify infill/shear wall below)

- ☐ Concrete Shear Wall (0)
- ☐ RM Shear Wall (0)
- ☐ PRM Shear Wall (2)
- ☐ URM Shear Wall (5)
- ☐ Plywood Shear Wall (5)
- ☐ Other: ________________ (5)

☐ Braced Frame (or cannot confirm moment frame) (0)

- ☐ Concrete Beams/Columns
- ☐ Precast Concrete Beams/Columns
- ☐ Steel Beams/Columns (heavy)
- ☐ Wood Beams/Columns
- ☐ Steel Beams/Columns (light)
- ☐ Steel Bar Joist and Concrete or RM Columns

☐ Shear Wall of Braced Frame; bracing or support is provided by:

- ☐ Concrete Shear Wall (0)
- ☐ RM Shear Wall (0)
- ☐ PRM Shear Wall (2)
- ☐ URM Shear Wall (5)
- ☐ Plywood Shear Wall (5)
- ☐ Other: ________________ (5)

☐ Load Bearing Wall System

- ☐ Concrete Walls (0)
- ☐ RM Walls (0)
- ☐ PRM Walls (4)
- ☐ URM Walls (6)
- ☐ Framed Walls (wood or metal stud) (6)
- ☐ Other: ________________ (6)

Elevated Floor or Roof Deck Systems (check all that apply) — **NO SCORE**

☐ Concrete Beams & Slab	☐ Concrete Flat Slab	☐ Precast Concrete Deck
☐ Steel Deck with Concrete	☐ Steel Deck with Insulation Only	
☐ Diagonal Sheathing	☐ Plywood Sheathing	☐ Wood Joists/Beams
☐ Wood Trusses	☐ Wood Plank	☐ Concrete Plank
☐ Concrete Waffle Slab	☐ Open Web Steel Joist	☐ Steel Beam

Evaluator's Name: ________________ Date of Evaluation: ________________

Site Name: ________________

Do the connections in the structural systems provide a continuous load path for all loads (gravity, uplift, lateral)?

☐ Yes (0) ☐ No (10)

If YES, identify the following connections:

Actual connectors of the roof structure and the spacing ____________________

____

Actual connectors between the roof and wall and the spacing ____________________

____

Connection Details for Refuge Area (check at least one item in each column)

	Roof to Roof Structure	Roof Structure to Wall Structure	Within Wall	Walls to Foundation
Reinforcing Steel	☐ (0)	☐ (0)	☐ (0)	☐ (0)
Welded (not tack)	☐ (0)	☐ (0)	☐ (0)	☐ (0)
Bolted	☐ (0)	☐ (0)	☐ (0)	☐ (0)
Metal Clips/Fasteners	☐ (1)	☐ (1)	☐ (1)	☐ (1)
Metal Hangers	☐ (1)	☐ (1)	☐ (1)	☐ (1)
Self Tapping Screws	☐ (1)	☐ (1)	☐ (1)	☐ (1)
Wire Fastener	☐ (2)	☐ (2)	☐ (2)	☐ (2)
Nailed	☐ (4)	☐ (4)	☐ (2)	☐ (4)
Other: __________ (possible tack weld)	☐ (5)	☐ (5)	☐ (5)	☐ (5)
Gravity Connection	☐ (6)	☐ (6)	☐ (6)	☐ (6)
Unknown	☐ (6)	☐ (6)	☐ (6)	☐ (6)

If walls are masonry units, are they grouted? Which cells are grouted (every cell, every 4th cell, etc.?

____

NO SCORE

Evaluator's Name: ____________________ Date of Evaluation: ____________________

Site Name: ____________________

For all unreinforced masonry walls, both load-bearing and non-load-bearing-fill in the blanks and answer the following two questions. Maximum height: ____________ Longest span: ____________ Thickness: ____________	**NO SCORE**
Is the maximum wall height/wall thickness (h/t) ratios for **unreinforced masonry walls (URM)** in excess of those noted in AFM 32-1095, page G-63 (see chart below.) ☐ Yes (5) ☐ No (0) ☐ Not applicable (0)	
Is the maximum wall length/wall thickness (l/t) ratios for **unreinforced masonry walls (URM)** in excess of those noted in AFM 32-1095, page G-63 (see chart below). (Measure longest span between column or pilaster supports or from end wall to wall opening.) ☐ Yes (5) ☐ No (0) ☐ Not applicable (0)	

NOTE: Additional guidance concerning the design and construction of masonry walls is provided in *Design of Conrete Masonry Warehouse Walls*, TEK 37, published by the National Concrete Masonry Association.

Allowable Value of Height-to-Thickness Ratio of URM Walls in High Wind Regions

Wall Types	Maximum l/t or h/t	
	Solid or Solid Grouted	All Other
Bearing Walls		
Walls of one-story buildings	16	13
First-story wall of multi-story building	18	15
Walls in top story of multi-story building	13	9
All other walls	16	13
Nonbearing Walls (Exterior and interior[1])	15	13
Cantilever Walls	3	2
Parapets	2	1 1/2

[1] Interior wall ratio should be the same as the exterior wall ratio due to the risk of internal pressure through breached openings.

Chart from Air Force Manual (AFM) 32-1095: Structural Evaluation of Existing Buildings for Seismic and Wind Loads, page G-63.

What are the debris hazards (choose all that apply): ☐ Large light towers (such as for an athletic field) and/or antennas within 300 ft of structure? (2) ☐ Portable classroom/trailers, small light frame buildings, HVAC units within 300 ft of the structure? (4) ☐ Unanchored fuel tanks within 300 ft of structure? (5)	
Is the refuge area located such that occupants must go outdoors to get to it? ☐ No (0) ☐ Yes (2)	

Evaluator's Name: ______________________ Date of Evaluation: ____________

Site Name: ______________________________

If the refuge area is a section of a building, are the wall systems separated from the remainder of the building structure with expansion joints? ☐ Yes (0) ☐ No (3)	
Does the refuge area have its own roof system (i.e., the roof does not extend over other sections of the building outside the refuge area or is separated by joints)? ☐ Yes (0) ☐ No (5)	
Is the height of the refuge area roof less than 30 feet above ground level? ☐ Yes (0) ☐ No (2)	
Is there a roof span in the refuge area longer than 40 feet from support to support? ☐ Yes (10) ☐ No (0)	
Is the pitch of the roof less than 30^{0} or less than 6/12 pitch? ☐ Yes (4) ☐ No (0)	
Are there any parapet walls taller than 3 feet (as compared to the adjacent roof level)? If yes, check any of the following that apply. ☐ Structurally attached to the refuge area (2) ☐ Adjacent egress routes (if parapet walls collapse, may block egress routes to the refuge area) (2)	
Does a roof overhang exist that is more than 2 feet wide? ☐ Yes (2) ☐ No (0)	
STRUCTURAL ISSUES SUBTOTAL =	

Evaluator's Name: ______________________ Date of Evaluation: ______________

Site Name: ______________________________________

CLADDING AND GLAZING ISSUES	
What is the percentage of windows and doors on the outer perimeter of the refuge area? ☐ no windows/protected doors (0) ☐ no windows/unprotected doors (1) ☐ 0% - 1% (1) ☐ 2% (2) ☐ 3% - 4% (4) ☐ 5% - 6%(6) ☐ 7% or more (10)	
Are doors to the refuge area secured at top and bottom with connections to resist suction effects that may pull the doors open (3-point latches)? ☐ Yes (0) ☐ No (10)	
Are there skylights or overhead atrium glass or plastic? ☐ Yes (5) ☐ No (0)	
What is the roof covering on the refuge area? **NOTE: If more than one material type is used on the roof, choose the one with the highest penalty.** ☐ Storm-resistant shingles (0) (greater than 100 mph rating) ☐ No roof covering (0) ☐ Traditional metal roofing (1) ☐ Built-up roof, without ballast (1) ☐ Single-ply membrane without ballast (1) ☐ Asphalt/metal shingles (1) ☐ Built-up roof, with stone ballast (2) ☐ Single-ply membrane with ballast (2) ☐ Wood shingles and shakes (2) ☐ Clay tile (2) ☐ Material other than those listed above (2)	
CLADDING AND GLAZING ISSUES SUBTOTAL =	

Evaluator's Name: ______________________ Date of Evaluation: ____________

Site Name: ______________________________________

ENVELOPE PROTECTION	
Is there roof mounted equipment (e.g., air handling units, fans, large satellite dishes, large equipment screens/shields) that may separate from the roof, leaving large holes or openings? ☐ Yes (5) ☐ No (0)	
☐ Are there buildings with roof gravel within 300 ft of the structure? (including building site itself) (2) ☐ Are there debris generating sources (e.g., lumber yards, nurseries, and junk yards) within 300 ft of the structure? (4) ☐ Is the refuge area vulnerable to trees, telephone poles, light poles, and other potential missiles? (4)	
What is the material on the exterior walls of the refuge area (excluding window and door systems)? ☐ Concrete (0) ☐ RM (0) ☐ PRM (4) ☐ Brick & block composite wall with reinforcing steel @ 4'-0" O/C (6) ☐ 3-wythes of solid masonry brick (6) ☐ URM (8) ☐ Metal/vinyl siding (10) ☐ Metal panels (pre-engineered metal building) (10) ☐ Wood or metal studs with drywall (12) ☐ Combination (other than EIFS) (12) ☐ EIFS (on substrate other than reinforced concrete or RM) (15)	
What is the material of the roof deck/elevated floor at the refuge area? ☐ Reinforced concrete at least 6 inches thick (0) ☐ Metal deck at least 14 gauge (0) ☐ Reinforced concrete at least 3 inches thick (2) ☐ Metal deck at least 20 gauge (4) ☐ Wood panels at least 1 inch thick (4) ☐ Cement fiber board/deck (tectum) (6) ☐ Metal deck 22 gauge or higher (8) ☐ Wood panels at least ½ inch thick (8) ☐ Other (10)	

Evaluator's Name: ____________________ Date of Evaluation: ____________

Site Name: ________________________________

Will the structure adjacent to the refuge area or surrounding it pose a threat if subject to collapse (structural components become debris that creates impact loads on the refuge area)? Specify. ☐ Yes (5) ☐ No (0)	
Are there large, roll-down or garage type doors (metal, wood, plastic) on the exterior of the refuge area? ☐ Yes (5) ☐ No (0)	
In what wind zone region is the school located based on the Wind Zones Map provided in Figure 1? ☐ Zone I [130 mph] (4) ☐ Zone II [160 mph] (6) ☐ Zone III [200 mph] (8) ☐ Zone IV [250 mph] (10)	
ENVELOPE PROTECTION SUBTOTAL	

Evaluator's Name: __________ Date of Evaluation: __________

Site Name: __________

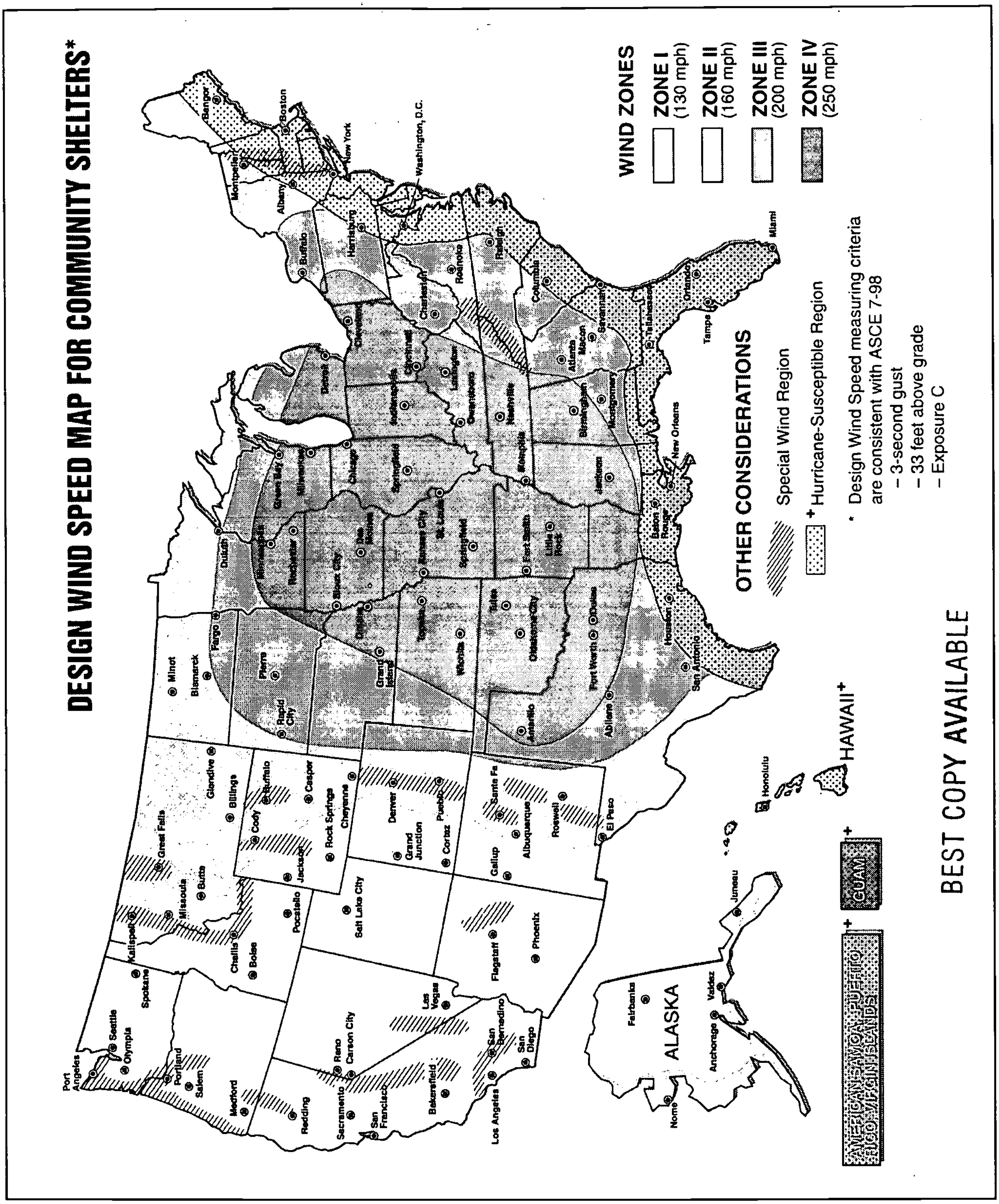


Figure 1: Design wind speed map for community shelters (Federal Emergency Management Agency). Additional information about wind zones is presented in Chapter 10 of *Design and Construction Guidance for Community Shelters*, FEMA 361.

Evaluator's Name: ______________________________ Date of Evaluation: ______________

Site Name: ____

NON-STRUCTURAL ISSUES	
Does a combustible gas line run through the refuge area? ☐ Yes (10) ☐ No (0) ☐ Unknown (10)	
Is there a back-up power source/generator? ☐ Yes (0) ☐ No (8) If YES, what is the power source: ☐ Battery powered (0) ☐ Other power (indicate fuel type) (2) Is there an automatic transfer switch? ☐ Yes (0) ☐ No (2) What is the duration of lighting under the back-up power source? ☐ 0-2 hours (2) ☐ 3-6 hours (1) ☐ 7 or more hours (0)	
If the back-up power supply is not within the refuge area, is it in a place where it will be protected during a high wind event (in an interior room, or below grade)? ____ ☐ Yes (0) ☐ No (5) ☐ Not Applicable (0)	
Is there a back-up communication system (if yes, list type)? ☐ Yes (0) ☐ No (2)	
Are bathrooms accessible within the refuge area? ☐ Yes (0) ☐ No (2)	
Is the refuge area ADA accessible? ☐ Yes (0) ☐ No (2)	
Is an operations plan in place for evacuation to a refuge area during a high-wind event? ☐ Yes (0) ☐ No (8) If YES, answer the following questions. Does the evacuation plan include practice drills? ☐ Yes (0) ☐ No (2) What type of warning signal is used to indicate a tornado drill?: Does it differ from a fire drill alarm? ☐ Yes (0) ☐ No (1) Can all occupants reach the candidate refuge area within 5 minutes? ☐ Yes (0) ☐ No (2) ☐ Unknown (2) List time: ____	
NON-STRUCTURAL SUBTOTAL =	
TOTAL WIND HAZARD SCORE =	

Evaluator's Name: ____ Date of Evaluation: ____

Site Name: ____

FLOOD HAZARD CHECKLIST

Address the following evaluation statements, giving the most appropriate answer for each question. After selecting the appropriate answer, take the score for that answer (# in the parentheses) and enter it into the score block for that question. Evaluation judgment is subject to limitations of visual examination. Elevations are required only if a flood hazard has been identified at the building site. If no flood hazard exists at the site, answer all flood-related questions "not applicable." **After, all questions have been appropriately scored, sum the score column and determine the final flood hazard score for the building/structure.**

QUESTION SCORE	SCORE
FLOOD HAZARD ISSUES	
What is the Base Flood Elevation (BFE) at the building site?* ______ What is the 500-year flood elevation at the building site?** ______ Flood Hazard Zone: ______ Community Panel No.: ______ Date Revised: ______ Not applicable (Explain): ______	NO SCORE
Is there a history of floods at the building site? ☐ Yes (5) ☐ No (0) ☐ Unknown (5) ☐ Not applicable (0)	
Is there a history of drains (storm or sanitary) backing up due to flooding? ☐ Yes (2) ☐ No (0) ☐ Unknown (2) ☐ Not applicable (0)	
Does the surrounding topography contribute to flooding in low-lying areas? Are there poor drainage patterns, basement stairwells, etc.? ☐ Yes (5) ☐ No (0)	
Are access roads to the building site sufficiently elevated and expected to not be closed during periods of high water (based on local flooding history and/or FIRM panel information)? ☐ Yes (0) ☐ No (2)	
Is the building within the 100-year floodplain and/or 500-year floodplain? ☐ Yes - 100-year and 500-year floodplains (10) ☐ Yes - 500-year floodplain only (5) ☐ No - Outside 500-year floodplain (0)	
If the building is within a 500-year floodplain, complete the following. If not, STOP HERE and skip to page 20 for STRUCTURAL SEISMIC HAZARD CHECKLIST.	

* BFEs are shown on the Flood Insurance Rate Map (FIRM) for the community.

** 500-year flood elevations are not shown on the FIRM; they are provided in the Flood Insurance Study (FIS) report for the community.

Evaluator's Name: ______ Date of Evaluation: ______

Site Name: ______

STRUCTURAL ISSUES ***	
What is the building/structure type? ☐ Concrete (0) ☐ RM (2) ☐ Steel (2) ☐ PRM (5) ☐ URM (8) ☐ Wood (10) ☐ Unknown (10)	
What is the elevation of the lowest floor/level of the building? ______ Is this elevation: ☐ Above the 500-year flood elevation (0) ☐ Above the BFE, below the 500-year flood elevation (4) ☐ Below the BFE or unknown (8) ☐ Not applicable (0)	
What is the elevation of the second lowest floor of the building? ______ Is this elevation: ☐ Above the 500-year flood elevation (0) ☐ Above the BFE, below the 500-year flood elevation (5) ☐ Below the BFE or unknown (10) ☐ Not applicable (0)	
If the lowest floor is below the 500-year flood elevation, are there openings in the walls to allow water to pass through the wall, thus avoiding pressure buildup on foundation and first floor walls? ☐ Yes (0) ☐ No (5) ☐ Not applicable (0)	
Is the space below the 500-year flood elevation used for classroom or office space? (If this area is used for storage, access, and parking only, answer "No"). ☐ Yes (2) ☐ No (0) ☐ Not applicable (0)	
Is the building material below the 500-year flood elevation constructed of entirely flood-resistant material? ☐ Yes (0) ☐ No (2) ☐ Not applicable (0)	
FACILITY AND UTILITY ISSUES	
Are the heating, electrical, and other utilities located in a basement or on a slab area that is below the 500-year flood elevation? ☐ Yes (4) ☐ No (0) ☐ Not applicable (0)	
Is there a method of removing flood waters from the building (e.g., sump pump)? What is the size and capacity of the pump? ☐ Yes (0) ☐ No (4) ☐ Not applicable (0)	
TOTAL FLOOD HAZARD SCORE =	

**** Ensure that all structure elevations that are compared to either Base Flood Elevations (BFEs) or 500-year flood elevations are referenced to the vertical datum stated on the FIRM panel. (Do not compare local benchmarks to MSL, NGVD 1929, etc.)

Evaluator's Name: ______ Date of Evaluation: ______

Site Name: ______

STRUCTURAL SEISMIC HAZARD CHECKLIST

Address the following evaluation statements, giving the most appropriate answer for each question. After selecting the appropriate answer, take the score for that answer (# in the parentheses) and enter it into the score block for that question. Evaluation judgment is subject to limitations of visual examination and availability of plans. (NOTE: This checklist is based on the guidelines set forth in the FEMA publication *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*, FEMA 154. One significant difference is the scoring procedure used in this manual. Do not compare a building scored on this checklist system with a building scored according to the procedure in FEMA 154. The comparison will not be valid.) **After, all questions have been appropriately scored, sum the score column and determine the final structural seismic hazard score for the building/structure.**

QUESTION SCORE	
See the Seismic Zone Map of the United States (Figure 2 on page 21) to determine the seismic zone of building locale.	
Is the building located in the unshaded area on the Seismic Activity Zone map (Figure 2) and was it designed by a design professional? ☐ Yes (0) ☐ No (2) If yes, further inspection within the seismic checklist is not necessary. STOP HERE. Is the building located in a Seismic Activity Zone (shaded area on Seismic Activity Zone map in Figure 2)? ☐ Yes (5)	
If yes, complete all remaining questions on this checklist. What is the building/structure type? ☐ Wood (10) ☐ RM & PRM (12) ☐ Steel (12) ☐ Concrete (14) ☐ Pre-cast "Tilt-up" Concrete (15) ☐ URM (17) ☐ Unknown (20)	

Evaluator's Name: ______________________ Date of Evaluation: __________

Site Name: ______________________

Add penalty points for deficiencies as noted during inspection. Select one column based on the building type determined in the previous question. Under each column, circle the penalty points if they apply for the criteria listed. (Use descriptions provided on the following page when filling out the matrix below.) When complete, sum the penalties that have been circled and place that total in the score box at right.

Bldg. Characteristic	RM & PRM	URM	Steel	Wood	Conc.	Pre-cast	UNK
High Rise	1.0	0.5	1.0	N/A	1.0	0.5	1.0
Poor Condition	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Vert. Irreg.	0.5	0.5	0.5	0.5	1.0.	1.0	1.0
Soft Story	2.0	2.0	2.0	1.0	2.0	2.0	2.0
Plan Irreg.	2.0	2.0	1.5	2.0	1.5	2.0	2.0
Pounding	N/A	N/A	0.5	N/A	0.5	0.5	0.5
Heavy Cladding	N/A	N/A	N/A	N/A	1.0	1.0	1.0
Post Benchmark	2.0	N/A	2.0	2.0	2.0	2.0	2.0

TOTAL STRUCTURAL SEISMIC HAZARD SCORE =

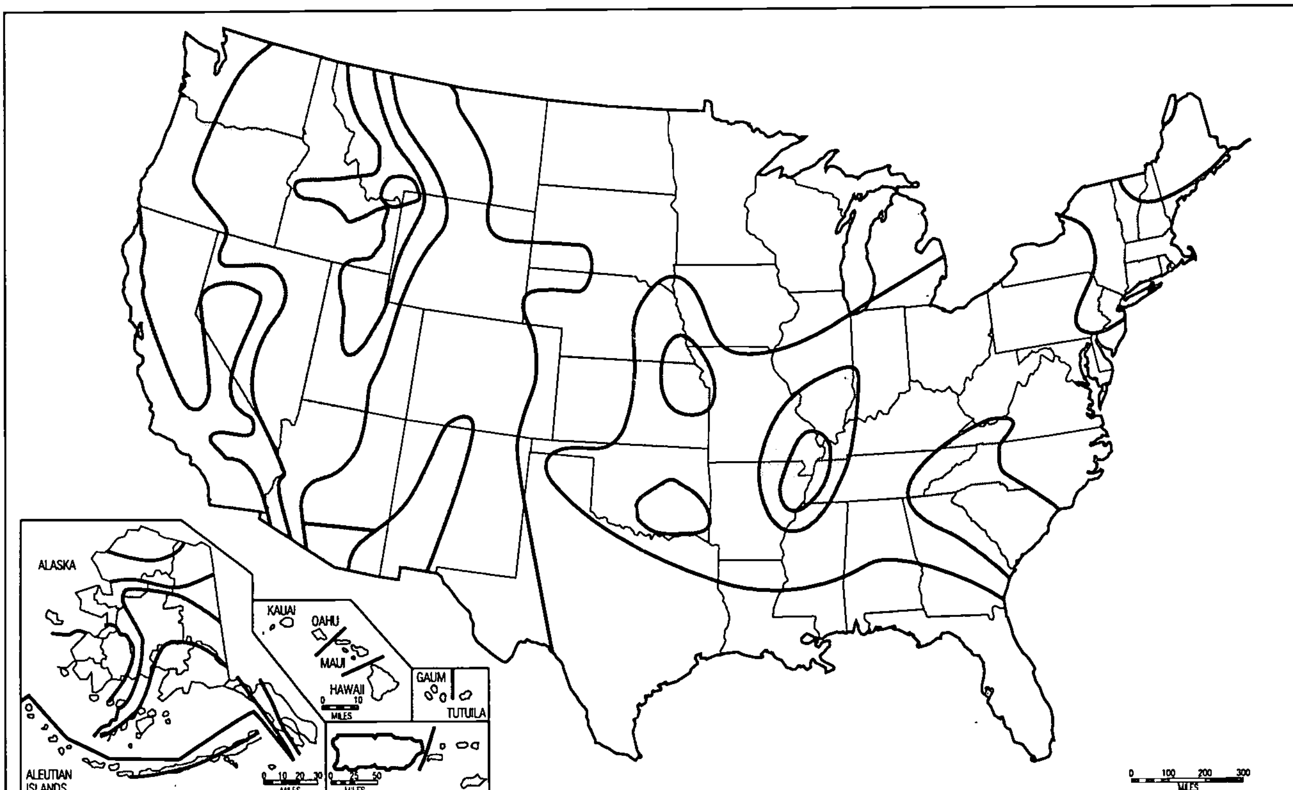


Figure 2 Seismic Activity Zone Map of the United States.

NOTE: This map is based on data compiled from the 1997 UBC and the 1997 NEHRP spectral response maps for a 0.2-second response. This map should be used for multi-hazard evaluation only. If seismic design calculations are required, the designer should use the 2000 IBC or the 1997 NEHRP provisions (FEMA 273).

Evaluator's Name: ______________________ Date of Evaluation: __________

Site Name: ______________________

Explanation of Building Characteristics

High Rise:
For the purposes of this checklist, a wood frame structure will not be considered a high-rise building. For buildings constructed of masonry units (i.e., brick, block, etc.) if the building is five stories and taller, it is considered a high-rise. For all remaining building types, the building must be eight stories or taller to be considered a high-rise building. If the building is determined to be a high-rise, assess penalty.

Poor Condition:
A building will be considered to be in poor condition if the building condition for the appropriate building type has been observed. Assess penalty if:

MASONRY JOINTS: The mortar can be easily scraped away from the joints by hand with a metal tool, and/or there are significant areas of eroded mortar.

MASONRY UNITS: There is visible deterioration of large areas of masonry units (i.e., significant cracking in the mortar joints, cracks through the masonry blocks themselves, voids or missing blocks or units, etc.).

DETERIORATION OF STEEL: Significant visible rusting, corrosion, tearing, or other deterioration in any of the steel elements in the vertical or lateral force-resisting system.

DETERIORATION OF WOOD: Wood members show signs of decay, shrinkage, splitting, fire damage, or sagging, or the metal accessories are deteriorated, broken, or loose. Wood members also showing signs or "tracks" from insect infestation.

DETERIORATION OF CONCRETE: Visible deterioration of concrete (i.e., cracking, spalling, crumbling, etc.) or significant exposure of reinforcing steel in any of the frame elements.

CONCRETE WALL CRACKS: Diagonal cracks in the wall element that are 1/4 inch or greater in width, are found in numerous locations, and/or form an X pattern.

CRACKS IN BOUNDARY COLUMNS: Diagonal cracks wider than 1/8 inch in concrete columns on any level of the structure.

Vertical Irregularity:
Are there "steps" in elevation of the building? Are some floors set back or do they extend outward from the footprint of the building? Are all of the walls of the building vertical or are there walls that slope inward or outward as viewed from the base of the building? Is the building located atop a small hill? If so, there are vertical irregularities; assess penalty.

Soft Story:
Are there open areas with tall ceilings on any floor of the building? Tall ceilings will typically be 1.25 times greater in height than the height of the floor just above or just below. Does the first floor (first few floors) contain parking areas, shops, large common areas, or lobbies? Is the first floor of the building taller than the other floors of the building? Are large windows (floor to ceiling) or open areas present in one or all walls of the building? If any of the above elements are observed, the building is said to have a soft story; assess penalty. Note: One-story buildings do not have a soft story.

Plan Irregularity:
Does the building have a highly irregular floorplan? Is the floorplan of the building an "L," "E," "H," "+," "T," or other such irregular configuration? Is the building long and narrow; length/width ratio greater than 2:1? If so, there are plan irregularities; assess penalty.

Pounding:
How close is the next adjacent building? Are the floors of two adjacent buildings at different elevations? An adjacent building presents a threat of pounding if the lateral distance between the two buildings is less than 4" x # stories of the smallest building. For example, if a ten-story building and a four-story building are adjacent to one another, there is a potential pounding problem if the buildings are not more than 16" apart. (4" x 4 stories = 16" of separation required); assess penalty.

Large (& Heavy) Cladding:
Is the exterior of the building covered in large concrete, or stone panels? If large panels exist, were the connections that secure these panels designed for seismic requirements? If it cannot be positively determined that the connections were designed for seismic requirements, assume that they were not. If large panels are present and they have been determined to be connected with non-seismic connectors, cladding deficiencies exist; assess penalty.

Post Benchmark:
A building is considered to be "Post Benchmark" if it was designed after modern seismic provisions were accepted by the local building code or the code that has been specified by the local jurisdiction. If the building was not designed for seismic requirements or it is not known if the building was designed for seismic requirements, it is not post benchmark; assess penalty.

COMMON BUILDING TYPES AND GLOSSARY OF TERMS

The following is a guide for selecting the type of building/type of construction of the building evaluated. The primary designations that the building types are divided into are Wood, Steel, Concrete, Pre-Cast Concrete, Reinforced Masonry, Partially Reinforced Masonry, and Unreinforced Masonry.

BRACED FRAME

A building frame system in which all vertical and lateral forces are resisted by shear and flexure in the members, joints of the frame itself, and walls or bracing systems between the beams and columns. A braced frame is dependent on bracing, infill walls between the columns, or shear walls between the columns to resist lateral loads.

CONCRETE

These buildings have walls and/or frames constructed of reinforced concrete columns and beams. Reinforced concrete walls will be seen as smooth surfaces of finished concrete. If this is a concrete frame, concrete masonry units (CMUs) are often used as shear (internal) walls placed between the columns and the beams.

ENGINEERED STEEL (Heavy)

These buildings are constructed of steel beams and columns and use either moment or braced frame systems. These buildings are designed specifically for that site and are not a "pre-engineered" or "prefabricated" building.

LOAD BEARING WALL SYSTEM

A building structural system in which all vertical and lateral forces are resisted by the walls of the building. The roof structure will be attached to the walls of the building and any forces in the roof system will be transferred to the walls through this roof/wall connection.

MOMENT FRAME

A building frame system in which all vertical and lateral forces are resisted by shear and flexure in members and joints of the frame itself. A moment frame will not utilize bracing, infill walls between the columns, or shear walls between the columns to resist lateral loads.

PARTIALLY REINFORCED MASONRY (PRM)

These buildings have perimeter, bearing walls of reinforced brick or CMU and the vertical wall reinforcement is spaced at more than 8 inches apart and a maximum spacing of 72 inches apart. Reinforcing for these walls will not be evident when viewing the walls; this information may be attained by using reinforcement locating devices or from reviewing project plans. Roof systems will typically be constructed of wood members, steel frames and trusses, or concrete. They may also have roofs and floors composed of precast concrete.

PRE-CAST (Including Tilt-up Construction)

These buildings typically have Pre-cast and Tilt-Up Concrete that will run vertically from floor to ceiling/roof. These buildings often have pre-cast or cast-in-place concrete roof systems, but may have very large wood or metal deck roof systems. These buildings could also be Pre-cast Concrete Frames with concrete shear walls, containing floor and roof diaphragms typically composed of pre-cast concrete.

REINFORCED MASONRY (RM)

These buildings have perimeter, bearing walls of reinforced brick or CMU and the vertical wall reinforcement is spaced at a maximum spacing of 8 inches apart; if the reinforcement is in CMU walls, every cell must contain reinforcing steel and grout. Reinforcing for these walls will not be evident when viewing the walls; this information may be attained by using reinforcement locating devices or from reviewing project plans. Roof systems will typically be constructed of wood members, steel frames and trusses, or concrete. They may also have roofs and floors composed of precast concrete.

STEEL (Light/Pre-engineered)

These buildings, at a minimum, will have a frame of steel columns and beams. These buildings may be constructed with braced frames. These buildings may be "pre-engineered" and/or "prefabricated" with transverse rigid frames. Interior shear walls may exist between the columns and beams of the frame. In addition, exterior walls may be offset from the exterior frame members, wrap around them, and present a smooth masonry exterior with no indication of the steel frame.

UNREINFORCED MASONRY (URM)

These buildings have perimeter bearing walls of unreinforced brick or concrete-block masonry. Roof systems will typically be constructed of wood members, steel frames and trusses, or concrete. They may also have roofs and floors composed of precast concrete. Most masonry wall systems that were constructed prior to the 1970s are unreinforced masonry.

WOOD

These buildings are typically single or multiple family dwellings of one or more stories. Wood structures may also be commercial or industrial buildings with a large floor area and with few, if any, interior walls. Typically, all walls and roof systems are constructed of timber frames.

The following is a glossary of terms that has been provided to ensure clarity and provide definitions for terminology used in these checklists.

BASE FLOOD

The flood having a 1-percent probability of being equaled or exceeded in any given year; also referred to as the 100 year flood.

BASE FLOOD ELEVATION (BFE)

The elevation of the base flood in relation to the National Geodetic Vertical Datum of 1929 (or other vertical datum as specified). BFEs are shown on NFIP Flood Insurance Rate Maps (FIRMs) as either A zones or V zones.

CONTINUOUS LOAD PATH

A continuous load path can be thought of as a "chain" running through a building. The "links" of the chain are structural members, connections between members, and any fasteners used in the connections (such as nails, screws, bolts, welds, etc.). To be effective, each "link" in the continuous load path must be strong enough to transfer loads without breaking. Because all applied loads (gravity, dead, live, uplift, lateral, etc.) must be transferred to the foundation, the load path must connect to the foundation.

EXTERIOR INSULATION FINISHING SYSTEM (EIFS)

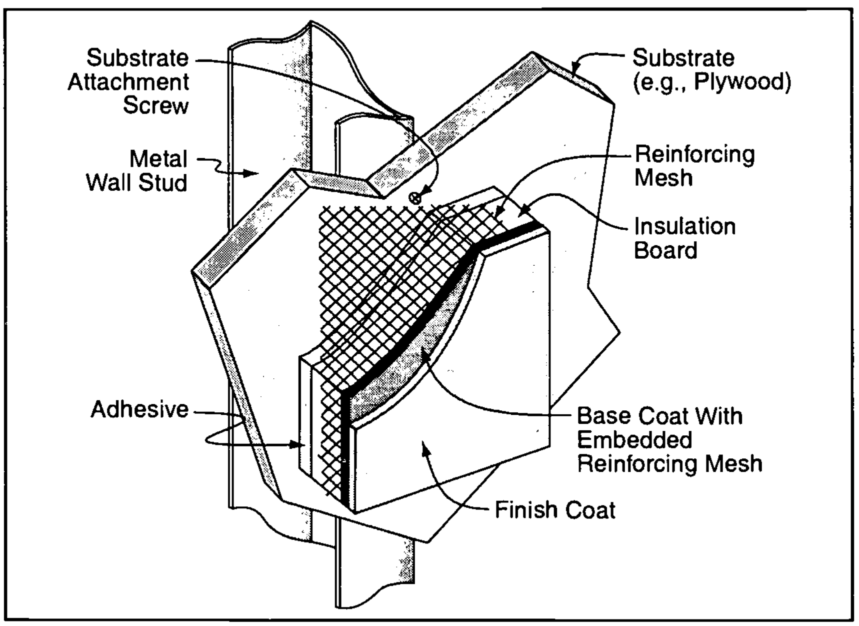


Figure 3: EIFS wall construction.

EIFS is a multi-layered exterior wall system used on both commercial buildings and homes. It comprises an insulation board mounted to a substrate. The insulation is protected by a plastic finish coat. Mesh reinforcing may be used to strengthen the system. Mesh reinforcing is located in a base coat that is between the insulation board and the finish coat.

500-YEAR FLOOD ELEVATION

The elevation of the 500-year flood in relation to the National Geodetic Vertical Datum of 1929 (or other vertical datum as specified). 500-year flood elevations can be found in NFIP Flood Insurance Study (FIS) reports. 500-year floodplains are shown on NFIP Flood Insurance Rate Maps (FIRMs) as either B zones or shaded X zones.

FLOOD INSURANCE RATE MAP (FIRM)

Insurance and floodplain management map issued by FEMA that identifies areas of 100-year flood hazard in a community. In areas studied by detailed analyses, the FIRM also shows BFEs and 500-year floodplain boundaries and, if determined, floodway boundaries.

FLOOD RESISTANT MATERIAL

Any building material capable of withstanding direct and prolonged contact with flood waters without sustaining significant damage. The term “prolonged contact” means at least 72 hours, and the term “significant damage” means any damage requiring more than low-cost cosmetic repair (such as painting).

MASONRY WALL: HEIGHT TO THICKNESS RATIO (h/t)

Height to thickness refers to the height of a masonry wall compared to the thickness of the wall. The height of the wall should be measured from the foundation up to the point at which the wall is laterally supported. In a one-story building, the maximum height will typically be found at the point at which a wall extends to the highest roof support. In a multi-story building, the tallest floor height will indicate the height of the wall. Inspection of a doorway section in a masonry wall will allow an evaluator to determine the thickness of the wall. The largest ratio that is found is the most critical.

MASONRY WALL: LENGTH TO THICKNESS RATIO (l/t)

Length to thickness refers to the length of a masonry wall compared to the thickness of the wall. The length of the wall is typically measured from a wall corner to the next adjacent wall corner. Wall spans, however, can be quite long. If there are any vertical columns in a wall, the length will then be measured from column to column or from vertical support to vertical support. Inspection of a doorway section in a masonry wall will allow an evaluator to determine the thickness of the wall. The largest ratio that is found is the most critical.

PARAPET

A parapet is a small wall located atop a building that extends above the roof level. Parapets are typically located along a wall face at the top of the roof. They are most commonly seen on flat roofs and are usually a few feet tall and will be a minimum of 8" thick. They are often constructed of unreinforced masonry and are susceptible to damage by lateral forces caused by wind and seismic forces.

TACK WELD

A small weld intended only to secure a building element (i.e., roof deck) in place during construction. If the type of weld cannot be determined, it should be considered no better than a tack weld and “Other” should be selected.

SUMMARY SCORE SHEET

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
WIND HAZARD SCORE										
Area 1 Total										
Structural										
Cladding/Glazing										
Envelope										
Non-structural										
Area 2 Total										
Structural										
Cladding/Glazing										
Envelope										
Non-structural										
Area 3 Total										
Structural										
Cladding/Glazing										
Envelope										
Non-structural										
Area 4 Total										
Structural										
Cladding/Glazing										
Envelope										
Non-structural										
Area 5 Total										
Structural										
Cladding/Glazing										
Envelope										
Non-structural										
Highest Wind Hazard Score										
Flood Hazard Score										
Seismic Hazard Score										
TOTAL SCORE										

Appendix C
Case Study I – Stand-Alone Community Shelter (North Carolina)

Overview

The severe flooding in the state of North Carolina produced by Hurricane Floyd caused substantial property damage leaving many residents homeless. Temporary housing was provided by the Federal Emergency Management Agency (FEMA) for the victims of the floods. Temporary manufactured home communities were set up to house those left homeless until such time that permanent homes would be available.

Conventional stick-built houses and manufactured homes are typically not designed to resist design wind speeds associated with tornadoes. In areas where extreme winds are common, community shelters are needed to protect the great numbers of people living in FEMA-provided housing. A project for the design of dual-use shelters intended to function as both community centers and shelters for residential neighborhoods was initiated to meet this need. The shelter design drawings and specifications for this project were also intended for use as case studies to provide guidance for design professionals.

NOTE

To design reinforced concrete shelters, designers may use either the main body of ACI 318 *Building Code Requirements for Structural Concrete* or the Alternate Design Method, Appendix A of ACI 318. For this case study, the designer chose to use the Alternate Design Method.

Efforts were made to involve design professionals from areas that experience high-wind events and require tornado shelters. The shelters were required to provide near-absolute protection from extreme winds, comply with local building codes, and serve as a community center. Design guidance from ASCE7-98 was used for the structural design. Site evaluations were performed to assess natural hazard risks, parking capacity, and to ensure proper access. In addition, an operations plan was developed specifying procedures, public education, and signage. The wind load analysis on which the designs were based, the operations plan, and the design drawings are provided in this appendix. A summary of design parameters is presented on Sheet S-1 of the plans.

ASCE 7-98 Wind Load Analysis for Community Shelter in North Carolina
Using Exposure C

General Data

$K_z = 0.85$	Velocity Pressure Exposure Coefficient (Table 6-5 of ASCE 7-98)
$I = 1.00$	Importance Factor (see Chapter 5 of this manual)
$V = 200$	Wind Speed (mph) from FEMA Wind Zone Map (Figure 2-2 in this manual)
$K_{zt} = 1$	Topographic Factor (Figure 6-2 of ASCE 7-98)
$K_d = 1.00$	Wind Directionality Factor (Table 6-6 of ASCE 7-98)

$h = 11.75$	Building Height (ft)
$L = 72$	Building Length (ft)
$B = 50$	Building Width (ft)

Velocity Pressure (Section 6.5.10 of ASCE 7-98)

$q_z = (0.00256)(K_z)(K_{zt})(K_d)(V^2I)$ $\quad q_z = 87.04$ psf

$q_h = qz$

$q_h = 87.04$ psf

External Pressure Coefficients for Walls (Figure 6-3 in ASCE 7-98)

$L/B = 1.44$	$C_{p1} = 0.8$	windward wall	$B/L = 0.69$	$C_{p1} = 0.8$	windward wall
	$C_{p2a} = -0.412$	leeward wall		$C_{p2b} = -0.5$	leeward wall
	$C_{p3} = -0.7$	side wall		$C_{p3} = -0.7$	side wall

Roof Pressure Coefficients (Figure 6-3 in ASCE 7-98)

$h/L = 0.16$	$C_{p4a} = -0.9$	from 0–5.9 ft from windward edge
	$C_{p4b} = -0.9$	from 5.9–11.75 ft from windward edge
	$C_{p5} = -0.5$	from 11.75–23.5 ft from windward edge
	$C_{p6} = -0.3$	more than 23.5 ft from windward edge

(**Note:** Let $C_{p4} = C_{p4a} = C_{p4b}$ due to roof geometry)

Gust Factor

G = 0.85

Internal Pressure Coefficients for Buildings (Table 6-7 in ASCE 7-98)

GC_{pipos} = 0.55 for partially enclosed buildings
GC_{pineg} = -0.55for partially enclosed buildings

Design Wind Pressure for Rigid Buildings of All Heights (Section 6.5.12.2.1 of ASCE 7-98)

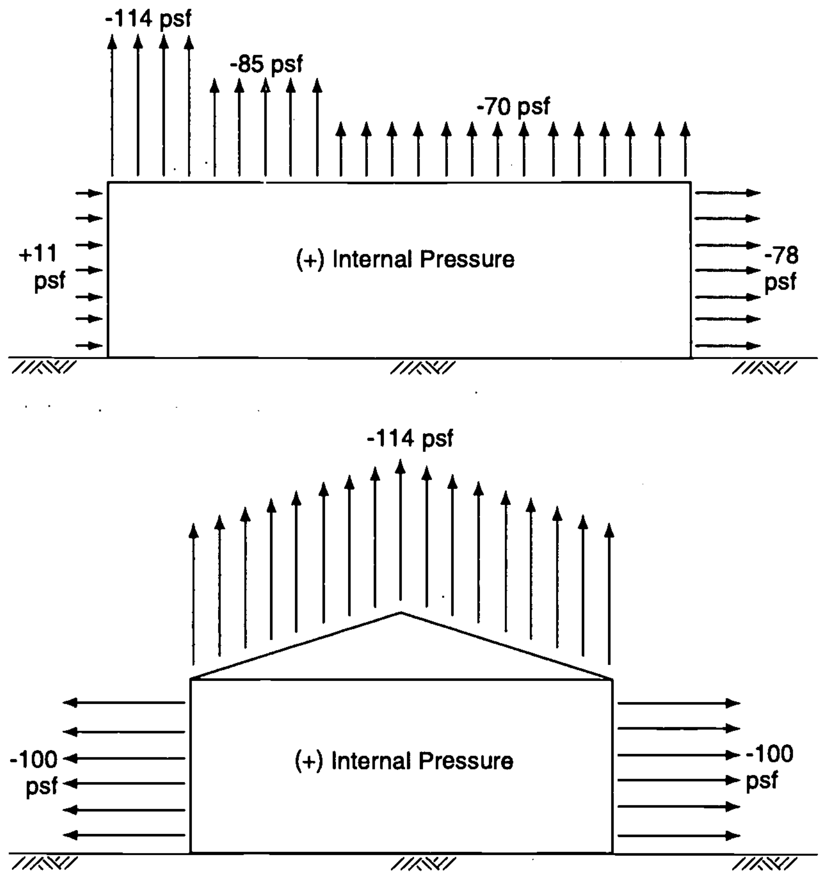
(for positive internal pressures)

$p_{wi} = (q_z)(G)(C_{p1} - q_h)(GC_{pipos})$	$p_{wi} = 11.32$	windward wall
$p_{lee2a} = (q_z)(G)(C_{p2a} - q_h)(GC_{pipos})$	$p_{lee2a} = -78.35$	leeward wall (wind parallel to ridge)
$p_{lee2b} = (q_z)(G)(C_{p2b} - q_h)(GC_{pipos})$	$p_{lee2b} = -84.86$	leeward wall (perpendicular to ridge)
$p_{side} = (q_z)(G)(C_{p3} - q_h)(GC_{pipos})$	$p_{side} = -99.66$	side wall
$p_{roof1} = (q_z)(G)(C_{p4} - q_h)(GC_{pipos})$	$p_{roof1} = -114.46$	roof pressures (0–11.75 ft from windward edge)
$p_{roof2} = (q_z)(G)(C_{p5} - q_h)(GC_{pipos})$	$p_{roof2} = -84.86$	roof pressures (11.75–23.5 ft from windward edge)
$p_{roof3} = (q_z)(G)(C_{p6} - q_h)(GC_{pipos})$	$p_{roof3} = -70.07$	roof pressures (more than 23.5 ft from windward edge)

(for negative internal pressures)

$p_{wi} = (q_z)(G)(C_{p1} - q_h)(GC_{pineg})$	$p_{wi} = 107.06$	windward wall
$p_{lee2a} = (q_z)(G)(C_{p2a} - q_h)(GC_{pineg})$	$p_{lee2a} = 17.39$	leeward wall (wind parallel to ridge)
$p_{lee2b} = (q_z)(G)(C_{p2b} - q_h)(GC_{pineg})$	$p_{lee2b} = 10.88$	leeward wall (perpendicular to ridge)
$p_{side} = (q_z)(G)(C_{p3} - q_h)(GC_{pineg})$	$p_{side} = -3.92$	side wall
$p_{roof1} = (q_z)(G)(C_{p4} - q_h)(GC_{pineg})$	$p_{roof1} = -18.71$	roof pressures (0–11.75 ft from windward edge)
$p_{roof2} = (q_z)(G)(C_{p5} - q_h)(GC_{pineg})$	$p_{roof2} = 10.88$	roof pressures (11.75–23.5 ft from windward edge)
$p_{roof3} = (q_z)(G)(C_{p6} - q_h)(GC_{pineg})$	$p_{roof3} = 25.68$	roof pressures (more than 23.5 ft from windward edge)

Figure C-1
Design wind pressures when wind is parallel to ridge with positive internal pressures (community shelter in North Carolina).



Notes:
1. Positive pressure values act against the building surface.
2. Negative pressure values act away from the building surface.
3. Wind direction is from left to right on the top figure and going into the page on the lower figure.

BUDGETARY COST ESTIMATE FOR THE NORTH CAROLINA SHELTER

ESTIMATED CONSTRUCTION COSTS (+/- 20%)
(SHELTER AREA = 3,600 Square Feet)

CONSTRUCTION ITEM	COST
• Site work and general requirements	$ 32,000
• Major structural system: footings, floors, columns, pilasters, beams, roof	$140,000
• Interior partitions	$ 17,500
• Doors and hardware	$ 8,100
• Painting, floor seal, exterior waterproofing	$ 37,500
• Roofing (EPDM) single ply	$ 15,000
• Toilet partitions and accessories (ADA)	$ 4,500
• Plumbing	$ 6,000
• Electrical	$ 31,500
• Mechanical	$ 30,000
TOTAL CONSTRUCTION COSTS	$322,000
Profit and Fees	$ 32,000
TOTAL ESTIMATED CONSTRUCTION COSTS	**$354,000**
UNIT COST (PER SQUARE FOOT [SF])	**$98.00/SF**

COMMUNITY DISASTER & TORNADO SHELTER OPERATIONS PLAN:
HURRICANE FLOYD HOUSING INITIATIVE, NORTH CAROLINA

DECEMBER 14, 1999

PREPARED FOR:
FEMA REGION IV
3003 Chamblee Tucker Road
Atlanta, GA 30341

PREPARED BY:
GREENHORNE & O'MARA, INC.
9001 Edmonston Road
Greenbelt, MD 20770

TABLE OF CONTENTS

COMMUNITY DISASTER AND TORNADO SHELTER OPERATIONS PLANS

Risk Assessment

Many states are at risk from tornadoes. North Carolina faces a significant threat from the effects of tornadoes. According to the National Oceanic and Atmospheric Administration (NOAA), the State of North Carolina averaged 29 tornadoes per year in the past decade. Between 1950 and 1995, 618 tornadoes occurred in the state, leading to 82 related fatalities and approximately 2,000 injuries (source: North Carolina Disaster Center). This Community Disaster & Tornado Shelter Operations Plan has been developed to help reduce the risk of death and injury to individuals.

Past Performance of Manufactured Housing During High-Wind Events

All buildings that are not designed for high winds are susceptible to damage from tornadoes. However, manufactured housing on non-permanent foundations is particularly vulnerable to high winds. The units can easily overturn or be displaced even if tie-down straps have been used and steps have been taken to securely anchor the home to its foundation. Foundation straps can fail from rust or corrosion, anchor failure, improper installation, or inability to resist wind forces. Foundation or anchor displacement can also be caused by strap or anchor pullout, loosening, or soil failure. In 1996, both manufactured housing and "site-built" conventional housing in North Carolina were severely damaged by Hurricane Fran. Tornadic winds are far more powerful and devastating than the hurricane-force winds encountered during Hurricane Fran and place occupants of any type of housing at risk of death or injury should a tornado strike the community.

In FEMA 342 (Midwest Tornadoes of May 3, 1999: Observations, Recommendations, and Technical Guidance), FEMA concluded, "Shelters are the best means of providing near-absolute protection for individuals who are attempting to take refuge in a tornado." Therefore, a multi-use community shelter has been designed to provide protection for this FEMA planned community in the event of a tornado or other extreme wind event.

DISASTER PROTECTION (WHAT TO DO)

The National Weather Service issues two types of tornado advisories: a **tornado watch** and a **tornado warning**.

Tornado Watch-

<u>A tornado watch means that conditions are favorable for the development of a tornado in your area and indicates the possibility of tornado occurrence.</u>

Tornado Warning-

<u>A tornado warning means that a tornado has actually been spotted or is strongly indicated on radar.</u>

If a **tornado watch** has been issued, be alert and listen closely for further developments and forecasts by your local weather service. The Community Disaster Management Team should implement their tornado Shelter Operations Plan and prepare to take action. When a **tornado warning** is broadcast, all residents should go immediately to the community shelter and follow procedures set forth by the Community Disaster Management Team. Once a warning is issued, there may be very little time before the onset of the tornado in your area.

The Community Disaster Management Team should post a list of Action Items within the shelter as a reminder to the community residents.

Disaster Management Team and Responsibilities

In order to implement the Shelter Operations Plan, it is necessary that a team be put together with members committed to performing various duties. Team members can take on multiple assignments as long as all tasks can be performed by the team member during an event. Cross training is recommended so that team members can assist each other if needed.

The following team members are responsible for implementing the Shelter Operations Plan:

Site Coordinator: ____

Contact numbers: ____________ / ______________ / ____________

Responsibilities:

- organizes and coordinates Community Disaster Plan
- ensures that personnel are in place to facilitate Shelter Operations Plan
- ensures that all aspects of Shelter Operations Plan are implemented
- develops community education and training program
- coordinates shelter evacuation practice drills and determines how many should be conducted in order to be ready for a real event
- conducts regular community meetings to discuss emergency planning
- prepares and distributes newsletters to residents
- distributes phone numbers of key personnel to residents

Assistant Site Coordinator: ____

Contact numbers: ____________ / ______________ / ____________

Responsibilities:

- performs duties of Site Coordinator when he/she is off site or unable to carry out responsibilities

Equipment Manager: ______________________________

Contact numbers: __________ / __________ / __________

Responsibilities:

- understands and operates all shelter equipment (this includes communications, lighting and safety equipment, and securing closure of shelter)
- maintains equipment year-round, ensuring that it will work properly during a tornado event
- informs Site Coordinator if equipment is defective or needs to be upgraded
- purchases supplies, maintains storage, and keeps inventory
- replenishes supplies to pre-established levels following a disaster

Signage Manager: ______________________________

Contact numbers: __________ / __________ / __________

Responsibilities:

- determines what signage and maps are needed to help residents get to the shelter in the fastest and safest manner possible
- prepares or acquires placards to be posted
- ensures that signage complies with ADA requirements
- provides signage in other languages if required
- works with Equipment Manager to ensure that signage is illuminated after dark and that all lighting will operate if power outage occurs

Notification Manager: ______________________________

Contact numbers: __________ / __________ / __________

Responsibilities:

- develops notification warning system that lets residents know they should proceed immediately to the shelter
- implements notification system when tornado warning is given

- ensures that non-English speaking residents understand notification (this may require communication in other languages or the use of pre-recorded tapes)
- ensures that residents who are deaf receive notification (this may require sign language, installation of flashing lights, or handwritten notes)

Field Manager: ______________________________

Contact numbers: ____________ / ______________ / ______________

Responsibilities:

- facilitates Evacuation Plan, ensuring that residents move to the shelter in an orderly fashion
- pre-identifies residents with special needs such as those that are disabled or that have serious medical problems
- arranges assistance for those residents that need help getting to the shelter (all complications should be anticipated and managed prior to the event)
- provides information to shelter occupants during the tornado event
- determines when it is safe to leave the shelter after a tornado event

Assistant Manager(s): ______________________________

Contact numbers: ____________ / ______________ / ______________

Responsibilities:

- performs duties of Equipment Manager, Notification Manager, Signage Manager, and Field Manager when he/she is off site or unable to carry out responsibilities

Community Disaster Planning

The Community Disaster Management Team should coordinate all activities and encourage community involvement. Residents should be given a copy of the Shelter Operations Plan and a list of all key personnel.

The first thing that must be determined is the best way to get residents to the shelter in the shortest amount of time without chaos. Parking is often a problem at community shelters. For the current shelter design, the disaster plan should instruct residents to proceed to the shelter on foot. Main pathways should be determined and laid out for the community. The Signage Manager should distribute maps showing the routes to the shelter as well as the shelter layout. In addition, the Signage Manager should place placards along the pathways to the shelter. Placards should also be installed inside the shelter that instruct occupants on how to properly secure the shelter door. All signage should be well lit and have a backup power source or be luminescent.

The Notification Manager shall determine a warning signal that residents will recognize and upon receiving the signal, go immediately to the shelter. The signal should be an audio system (a siren or alarm sound). As a backup to the audio system, a phone call chain, door-to-door notification, or some combination may be used. Another backup option is to install a phone bank that provides automatic phone service with recorded messages. Residents must be informed and understand the significance of the warning signal, and know how and where to proceed when they get the signal. They will learn the procedures by attending training sessions, practice drills, and reading newsletters issued by the Disaster Management Team.

The Equipment Manager should have knowledge of the operations of all equipment associated with the shelter. This includes radios, phones, transmitters, lighting, and safety equipment. The Equipment Manager is responsible for the closure of all shelter openings (doors, windows, etc.) prior to the event. All equipment must be maintained throughout the year. The Equipment Manager is also responsible for maintaining supplies (first-aid, water, and special needs) in a readiness state within the shelter. All supplies shall be replenished after each disaster event and a running inventory kept of available supplies.

The Field Manager should identify residents that need assistance in getting to the shelter. Arrangements should be made so that the residents that need help (whether it involves assigning people to move them, providing equipment, or just walking them) are provided for and brought to the shelter in time. Practice drills are critical for helping residents with special needs. The drills will highlight complications and allow time to plan ahead.

The Site Coordinator is responsible for resident education and training. This is accomplished through meetings, practice drills, and newsletters. The Site Coordinator will ensure that residents know what to do when a warning signal is transmitted. He/she must also ensure that all manager roles are assigned and that all managers understand and perform their duties.

Signage

- Well marked routes with proper lighting should be established that guide residents to the shelter.
- Placards should be posted along the route and throughout the community that direct residents to the shelter.
- Signs shall conform to ADA requirements and may be required in other languages.
- Maps showing homes and roads and the best route to the shelter should be provided for residents.
- A layout showing the shelter and its entrances should be prepared and distributed to residents.
- Emergency lights should be provided to enable all residents to reach the shelter in case of power outage.
- Post all restrictions that apply to those seeking refuge in the shelter (e.g., no pets, limits on personal belongings, etc.).

Shelter Operations Plan

When a tornado watch is issued, all key personnel should prepare to take action. When a tornado warning is broadcast, the Notification Manager shall transmit the warning signal alerting residents that they must go immediately to the shelter.

The Field Manager will assist all those with special needs, and direct all residents to the shelter. A count will be taken in the shelter and when all are present, all access doors will be closed tight. Time is crucial and a judgement call may be required as to when to close off the shelter if the tornado is imminent. This decision will be made by the Equipment Manager.

The Equipment Manager will monitor the radio at all times. When a broadcast is received indicating that it is safe to leave, the doors may be opened to allow residents to return to their homes. If anyone is injured, the Equipment Manager will radio or phone for help.

The time that residents are expected to stay in the shelter for a tornado event is approximately 2 hours.

Public Education and Training Plan

- The Site Coordinator will conduct several meetings throughout the year to educate residents on the risks from tornadoes, and the importance of complying with the Shelter Operations Plan. At these meetings, the Disaster Management Team should be introduced and the residents should be informed of each Manager's responsibilities. Details of the Shelter Operations Plan should also be presented (of most importance, are the routes to the shelter).
- The Site Coordinator will conduct at least two evacuation practice drills per year.
- Newsletters with updates and announcements should be prepared and distributed.
- The Disaster Management Team will communicate with local police, fire and rescue teams (PFR teams) :
    - to establish communications protocols to be followed before, during and after an event.
    - to provide the location of the shelter to PFR teams that may respond to the Site after an event, if so necessary.

Supplies

- Communications
  - NOAA weather radio or receiver for commercial radio broadcasts if NOAA broadcasts are not available
  - ham radio or emergency radio connected to police or fire and rescue system
  - cellular phone
  - battery-powered radio transmitter or signal-emitting device that can signal to local emergency personnel
  - portable generator with an uninterrupted power supply (UPS system) portable computer with modem and Internet capabilities
  - fax machine
  - television set
  - public address system
- Emergency Equipment
  - flashlights
  - batteries
  - fire extinguisher
  - blankets
  - pry-bars (to open doors that may be damaged or blocked by debris)
  - trash receptacles
  - trash liners with ties
  - tool kit
  - severe weather equipment
  - heaters
  - blankets

- First-aid
  - adhesive tape and bandages
  - scissors and tweezers
  - antiseptic solution
  - antibiotic ointments
  - aspirin and non-aspirin pain relievers
  - diarrhea medication
  - salts for fainting spells
  - towels
  - foldup cots
  - first-aid handbook
- Water
  - enough for shelter occupancy of 2 hours
- Infant Supplies (if needed)
  - disposable diapers
  - powder and ointments
  - Handi-Wipes
  - pacifiers
  - blankets

Special Needs

Some residents will require assistance in getting to the shelter. Identify who those people are, and determine the kind of help they will require. After a tornado warning has been issued, the Field Manager or his/her designee should make sure that those who require help are assisted.

Residents with medication needs should notify the Field Manager, who will ensure that the required medications are available during the evacuation to the shelter, and during the stay within the shelter.

Needs of Children

If the residential community includes children, they may require additional consideration. Infant needs should be part of the supplies stocked for the event. Additional items may be required to keep children calm and comfortable during this time.

Pets

No pets are permitted in the shelter during a tornado event.

List of Action Items (Shelter Operations Plan)

- Site Coordinator: ____________________ Contact Number: ____________
- Assistant Site Coordinator: ____________ Contact Number: ____________
- Equipment Manager: __________________ Contact Number: ____________
- Signage Manager: ___________________ Contact Number: ____________
- Notification Manager: ________________ Contact Number: ____________
- Field Manager: _____________________ Contact Number: ____________
- Tornado Watch
  - team is on alert
- Tornado Warning
  - team is activated
  - signal is sent to community to go to shelter
  - community is evacuated to the shelter
  - head count in shelter
  - monitor storm from within shelter
  - secure the shelter
  - monitor storm
  - leave shelter when safe
  - restock/clean shelter

COMMUNITY SHELTER

HURRICANE FLOYD HOUSING INITIATIVE

NORTH CAROLINA

DRAWING INDEX

COVER SHEET	
FUTURE SITE PLAN (FURNISHED BY OTHERS)	C1
FLOOR PLAN	A1
BUILDING DETAILS	A2
ELEVATIONS	A3
STRUCTURAL NOTES	S1
FOUNDATION PLAN	S2
SLAB REINFORCING & JOINT LAYOUT	S3
ROOF REINFORCING	S4
SECTIONS & DETAILS	S5
SECTIONS & DETAILS	S6
MECHANICAL PLAN & SCHEDULES	M1
POWER PLAN & SCHEDULES	E1
LIGHTING PLAN & SCHEDULES	E2
PLUMBING PLAN & SCHEDULES	P1

ACCESSIBILITY NOTES: ADA/ANSI A117.1

THE INTERNATIONAL SYMBOL OF ACCESSIBILITY SIGN SHALL BE DISPLAYED AT ALL ACCESSIBLE RESTROOM FACILITIES AND AT ACCESSIBLE BUILDING ENTRANCES UNLESS ALL ENTRANCES ARE ACCESSIBLE. INACCESSIBLE ENTRANCES SHALL HAVE DIRECTIONAL SIGNS INDICATING THE ROUTE TO THE NEAREST ACCESSIBLE ENTRANCE.

RECEPTACLES ON WALLS SHALL BE MOUNTED NO LESS THAN 15" ABOVE THE FLOOR. EXCEPTION: HEIGHT LIMITATIONS DO NOT APPLY WHERE THE USE OF SPECIAL EQUIPMENT DICTATES OTHERWISE OR WHERE ELECTRICAL RECEPTACLES ARE NOT NORMALLY INTENDED FOR USE BY BUILDING OCCUPANTS.

WHERE EMERGENCY WARNING SYSTEMS ARE PROVIDED, THEY SHALL INCLUDE BOTH AUDIBLE AND VISUAL ALARMS. THE VISUAL ALARMS SHALL BE LOCATED THROUGHOUT, INCLUDING RESTROOMS, AND PLACED 80" ABOVE THE FLOOR OR 6" BELOW CEILING, WHICHEVER IS LOWER.

DOORS TO ALL ACCESSIBLE SPACES SHALL HAVE ACCESSIBLE HARDWARE (i.e. LEVER-OPERATED, PUSH-TYPE, U-SHAPED) MOUNTED NO HIGHER THAN 48" ABOVE THE FLOOR.

FLOOR SURFACES SHALL BE STABLE, FIRM, AND SLIP-RESISTANT. CHANGES IN LEVEL BETWEEN 0.25" AND 0.5" SHALL BE BEVELED WITH A SLOPE NO GREATER THAN 1:2". CHANGES IN LEVEL GREATER THAN 0.5" REQUIRE RAMPS. CARPET PILE THICKNESS SHALL BE 0.5" MAX. GRATINGS IN FLOOR SHALL HAVE SPACES NO GREATER THAN 0.5" WIDE IN ONE DIRECTION. DOORWAY THRESHOLDS SHALL NOT EXCEED 0.5" IN HEIGHT.

GRAB BARS REQUIRED OF ACCESSIBILITY SHALL BE 1.25"-1.50" IN DIAMETER WITH 1.5" CLEAR SPACE BETWEEN THE BAR AND THE WALL.

ACCESSIBLE WATER CLOSETS SHALL BE 17"-19" FROM FLOOR TO THE TOP OF THE SEAT. GRAB BARS SHALL BE 36" LONG MINIMUM WHEN LOCATED BEHIND WATER CLOSET AND 42" MINIMUM WHEN LOCATED ALONG SIDE OF WATER CLOSET, AND SHALL BE MOUNTED 33"-36" ABOVE THE FLOOR.

ACCESSIBLE URINALS SHALL BE STALL-TYPE OR WALL HUNG WITH ELONGATED RIMS AT A MAXIMUM OF 17" ABOVE THE FLOOR.

ACCESSIBLE LAVATORIES SHALL BE MOUNTED WITH THE RIM NO HIGHER THAN 34" ABOVE THE FLOOR AND A CLEARANCE OF AT LEAST 29" ABOVE THE FLOOR TO THE BOTTOM OF THE APRON.

ACCESSIBLE SINKS SHALL BE MOUNTED WITH THE RIM NO HIGHER THAN 34" ABOVE THE FLOOR AND A CLEARANCE OF AT LEAST 27" HIGH, 30" WIDE, AND 19" DEEP UNDERNEATH SINK. THE SINK DEPTH SHALL BE 6.5" MAXIMUM.

HOT WATER AND DRAIN PIPES UNDER ACCESSIBLE LAVATORIES AND SINKS SHALL BE INSULATED OR OTHERWISE CONFIGURED TO PROTECT AGAINST CONTACT. THERE SHALL BE NO SHARP OR ABRASIVE SURFACES UNDER ACCESSIBLE LAVATORIES AND SINKS.

ACCESSIBLE LAVATORIES AND SINKS SHALL HAVE ACCESSIBLE FAUCETS (i.e. LEVER-OPERATED, PUSH-TYPE, ELECTRONICALLY CONTROLLED.)

WHERE MIRRORS ARE PROVIDED IN RESTROOM, AT LEAST ONE SHALL BE PROVIDED WITH ITS BOTTOM EDGE NO HIGHER THAN 40" ABOVE THE FLOOR.

COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

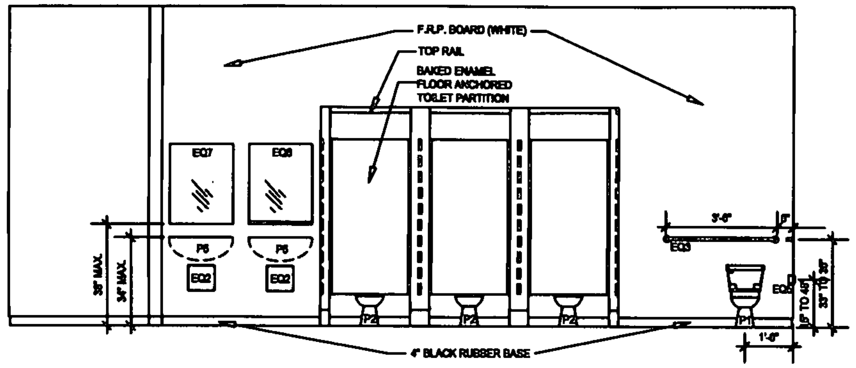
The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

COVER SHEET

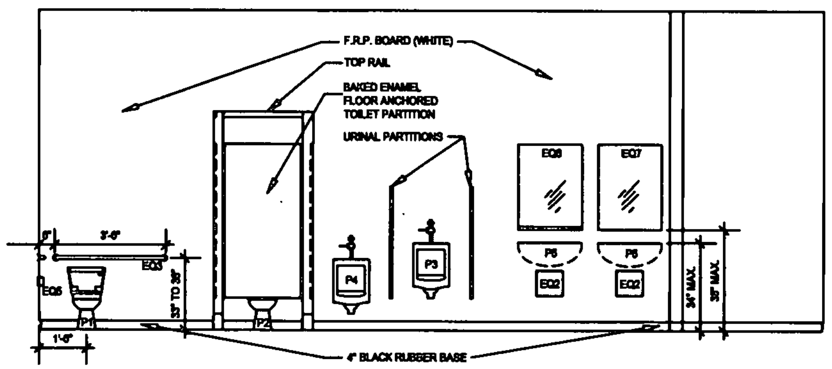
SHEET No.:
DATE: 14 DECEMBER 1999
REVISED: REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

BEST COPY AVAILABLE



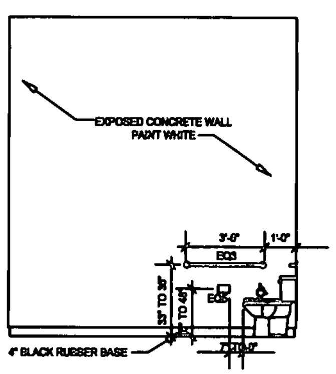
102 WOMENS RESTROOM
SCALE: 3/8" = 1'-0"



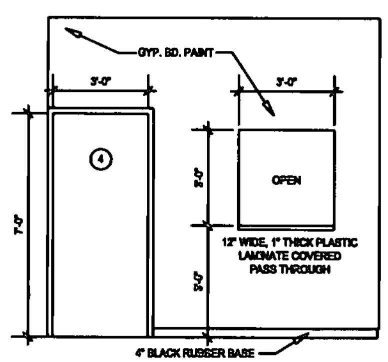
103 MENS RESTROOM
SCALE: 3/8" = 1'-0"

GENERAL NOTES:

1. ALL GYP. BOARD WALLS 1/2" THICK.
2. CONTRACTOR SHALL PROVIDE SOLID WOOD BLOCKING IN WALLS FOR ANCHORAGE OF SINKS, MIRRORS, PARTITIONS, ETC.
3. INTERIOR WALL CONSTRUCTION SHALL BE METAL FRAMING 25 GAUGE AT 16" ON CENTER.
4. F.R.P. BOARD SHALL BE INSTALLED USING ALL EDGE, CORNER & JOINT MATERIALS OF THE SAME COLOR.



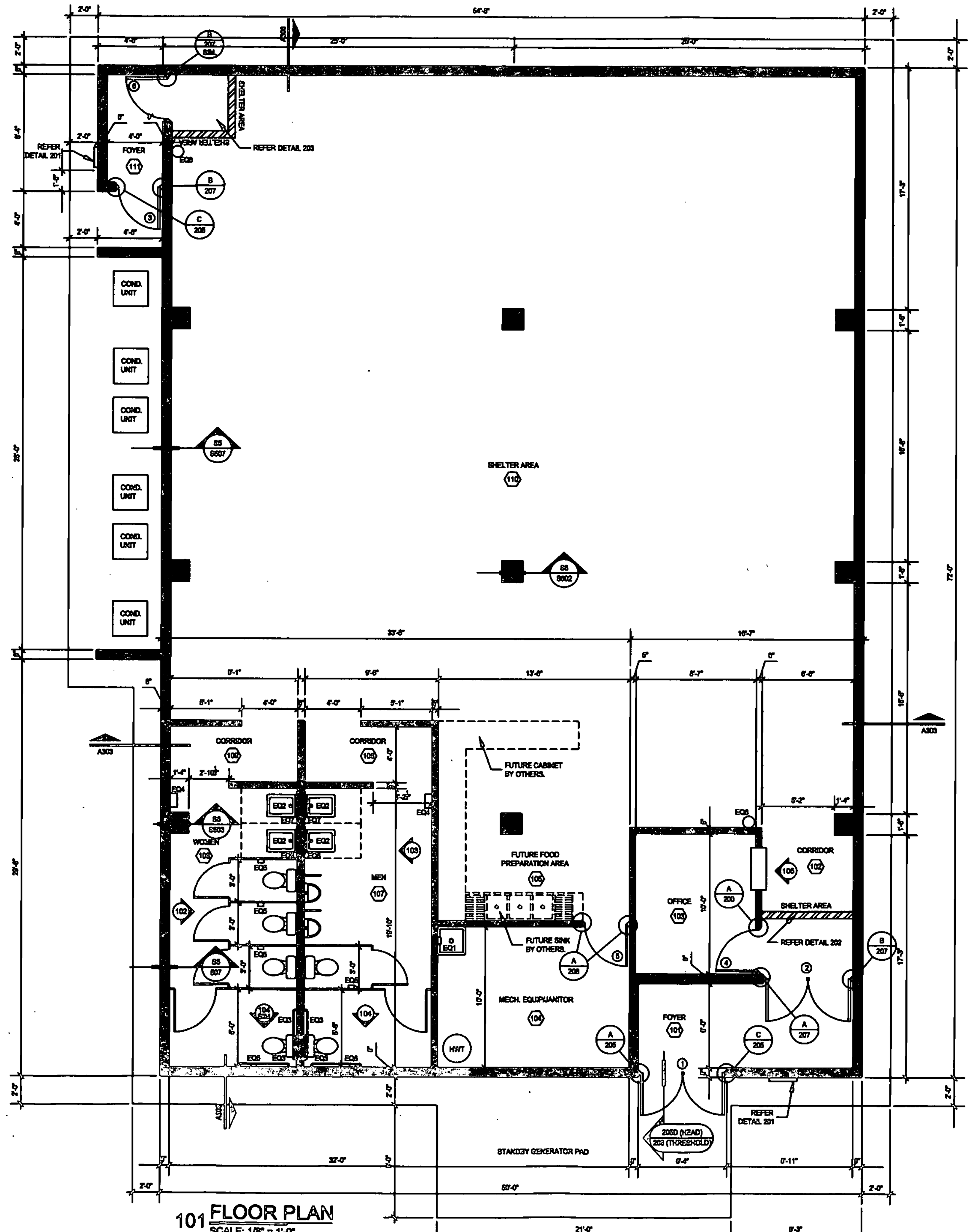
104 RESTROOM
SCALE: 3/8" = 1'-0"



105 CORRIDOR
SCALE: 3/8" = 1'-0"

EQUIPMENT SCHEDULE

ITEM	DESCRIPTION	MANUFACTURER	MODEL	REMARKS
EQ1	MOP HANGER	ELGER	24" LONG x 3"	STAINLESS STEEL WITH 3 RUBBER TOOL GRIPS
EQ2	DRAIN COVERS	PLUMBEREX	3011	
	VALVE AND SUPPLY COVERS	PLUMBEREX	3021	
	TAILPIECE COVERS	PLUMBEREX	3041	
EQ3	42" GRAB BARS	BRADLEY	MODEL 812 TYPE 304 001-42-2	
EQ4	TOWEL DISPENSER WASTE RECEPTACLE	BRADLEY	MODEL 2017-11 TYPE 304	30" DROP-IN, UP-FRONT CONTROLS, WHITE
EQ5	TISSUE DISPENSER	BRADLEY	MODEL 503	
EQ6	MIRROR	BRADLEY	7015-2430-2 24" x 30"	MIRROR WITH SHELF
EQ7	MIRROR	BRADLEY	782-2433-2	TILT MIRROR
EQ8	FIRE EXTINGUISHER	ANY		10LB. ABC WALL MOUNTED



101 FLOOR PLAN
SCALE: 1/8" = 1'-0"

BEST COPY AVAILABLE

COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

FLOOR PLAN

SHEET No.: A1	
DATE: 14 DECEMBER 1999	
REVISED:	REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

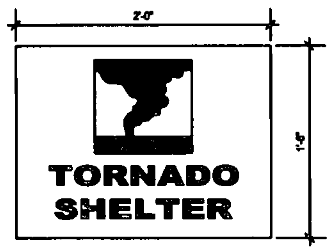
COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

ROOM FINISH SCHEDULE

MK	DESCRIPTION	FLOOR	BASE	WALL 1	WALL 2	WALL 3	WALL 4	CEILING	HEIGHT	REMARKS
101	FOYER	SEALED CONC.	NONE	EXPOSED CONCRETE PAINT	EXPOSED CONCRETE PAINTED	EXPOSED CONCRETE PAINTED	EXPOSED CONCRETE PAINTED	EXPOSED CONCRETE PAINTED	VARIES	
102	CORRIDOR	SEALED CONC.	NONE	—	EXPOSED CONCRETE PAINTED	EXPOSED CONCRETE PAINTED	GYP. BOARD PAINTED	EXPOSED CONCRETE PAINTED	VARIES	4" RUBBER BASE WALL 4
103	OFFICE	SEALED CONC.	4" RUBBER ALL WALLS	GYP. BOARD PAINTED	GYP. BOARD PAINTED	EXPOSED CONCRETE PAINTED	GYP. BOARD PAINTED	EXPOSED CONCRETE PAINTED	VARIES	
104	MEC. JANITORIAL EQUIP.	SEALED CONC.	4" RUBBER WALL (1, 2 & 4)	FRP BOARD	FRP BOARD & EXPOSED CONCRETE. PAINTED	EXPOSED CONCRETE PAINTED	FRP BOARD	EXPOSED CONCRETE PAINTED	VARIES	
105	FUTURE FOOD PREP. AREA	SEALED CONC.	4" RUBBER ALL WALLS	—	FRP BOARD	FRP BOARD	FRP BOARD	EXPOSED CONCRETE PAINTED	VAIRES	
106	CORRIDOR	SEALED CONC.	4" RUBBER	FRP BOARD	FRP BOARD	FRP BOARD	FRP BOARD	EXPOSED CONCRETE PAINTED	VARIES	
107	MEN'S RESTROOM	SEALED CONC.	4" RUBBER	FRP BOARD	FRP BOARD	EXPOSED CONCRETE PAINTED	FRP BOARD	EXPOSED CONCRETE PAINTED	VARIES	
108	WOMEN'S RESTROOM	SEALED CONC.	4" RUBBER	FRP BOARD	FRP BOARD	EXPOSED CONCRETE PAINTED	EXPOSED CONCRETE PAINTED	EXPOSED CONCRETE PAINTED	VARIES	
109	CORRIDOR	SEALED CONC.	4" RUBBER	FRP BOARD	FRP BOARD	FRP BOARD	EXPOSED CONCRETE PAINTED	EXPOSED CONCRETE PAINTED	VARIES	
110	SHELTER AREA	SEALED CONC.	NONE 4" RUBBER WALL 3	EXPOSED CONCRETE PAINT	EXPOSED CONCRETE PAINT	GYP. BOARD PAINTED	EXPOSED CONCRETE PAINT	EXPOSED CONCRETE PAINTED	VARIES	
111	FOYER	SEALED CONC.	NONE	EXPOSED CONCRETE PAINT	EXPOSED CONCRETE PAINTED	EXPOSED CONCRETE PAINTED	EXPOSED CONCRETE PAINTED	EXPOSED CONCRETE PAINTED	VARIES	

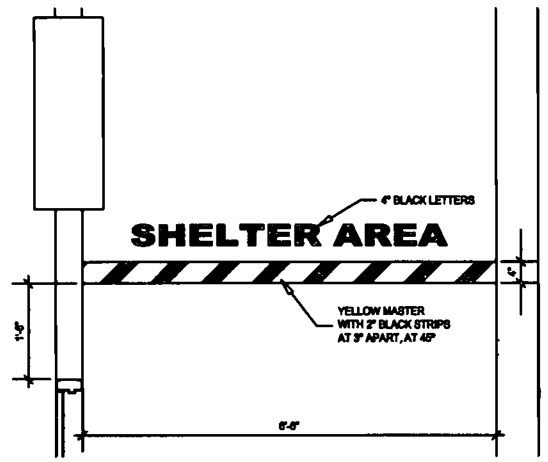
DOOR FINISH SCHEDULE

MK	TYPE	SIZE	MATERIAL	FINISH	FRAME	FINISH	GLAZING	HEAD	JAMB	TRESH	REMARKS
1	A	CECO MEDALLION PR 3'-0"x7'-0"x1 3/4" LEVEL4	14 ga. STEEL	PAINT	12 ga. STEEL	PAINT	NONE	205 D	205 A,B,C	206	14 ga. STEEL DOOR WITH 20 ga. RIBS.
2	A	CECO MEDALLION PR 3'-0"x7'-0"x1 3/4" LEVEL 4	14 ga. STEEL	PAINT	12 ga. STEEL	PAINT	NONE	205 D	207 A & B	NONE	14 ga. STEEL DOOR WITH 20 ga. RIBS.
3	B	CECO MEDALLION PR 3'-0"x7'-0"x1 3/4" LEVEL 4	14 ga. STEEL	PAINT	12 ga. STEEL	PAINT	NONE	205 D	205 B (SIM)	206 (SIM)	14 ga. STEEL DOOR WITH 20 ga. RIBS.
4	B	CECO MEDALLION 3'-0" x 7'-0" x 1¾" LEVEL 1	20 ga. STEEL	PAINT	16 ga. STEEL	PAINT	NONE	208 B	207 A	NONE	
5	B	CECO MEDALLION 3'-0" x 7'-0" x 1¾" LEVEL 1	20 ga. STEEL	PAINT	16 ga. STEEL	PAINT	NONE	208 B	208 B (SIM)	NONE	
6	B	CECO MEDALLION PR 3'-0"x7'-0"x1 3/4" LEVEL 4	14 ga. STEEL	PAINT	12 ga. STEEL	PAINT	NONE	205 D	207 A & B	NONE	14 ga. STEEL DOOR WITH 20 ga. RIBS.

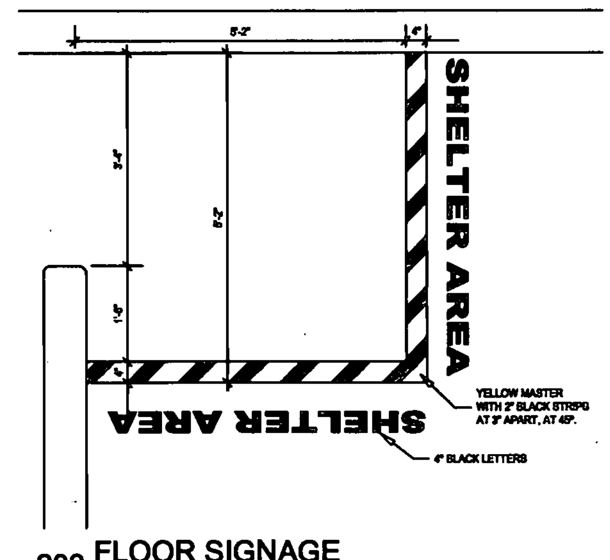


201 BUILDING I.D. SIGN
SCALE : ¾" = 1'-0"

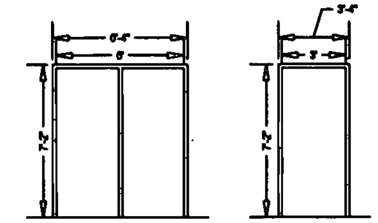
ALUMINUM SIGN BACKGROUND NON-REFLECTIVE. "TORNADO - SHELTER" AND LOGO SHALL BE REFLECTIVE USING 3M SCOTCHLITE DIAMOND GRADE REFLECTIVE SHEETING. YELLOW IN COLOR. VERIFY WITH MANUFACTURER THAT SIGN WILL GLOW FOR A MIN OF 6 HOURS, IN THE EVENT OF POWER LOSS.



202 FLOOR SIGNAGE
SCALE : ¾" = 1'-0"

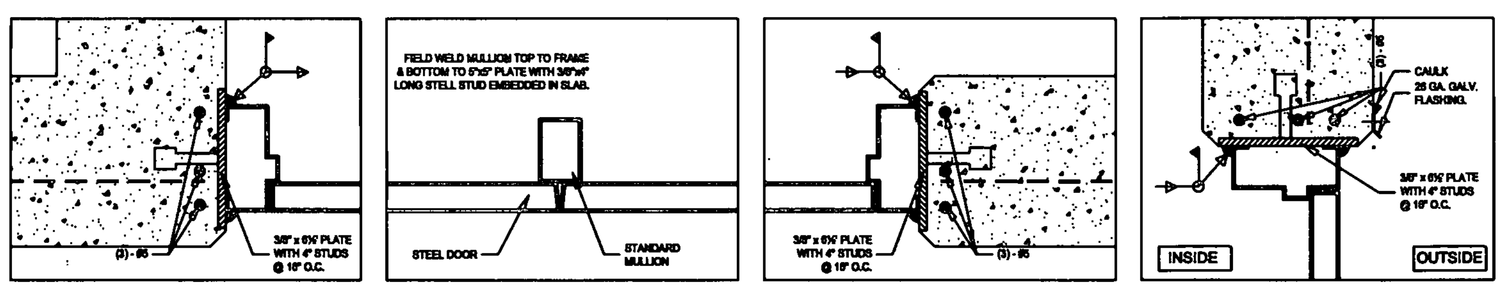


203 FLOOR SIGNAGE
SCALE : ¾" = 1'-0"



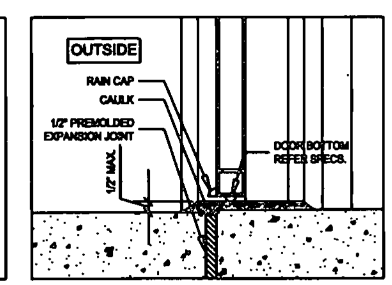
Ⓐ Ⓑ

204 DOOR TYPE
SCALE : ¼" = 1'-0"



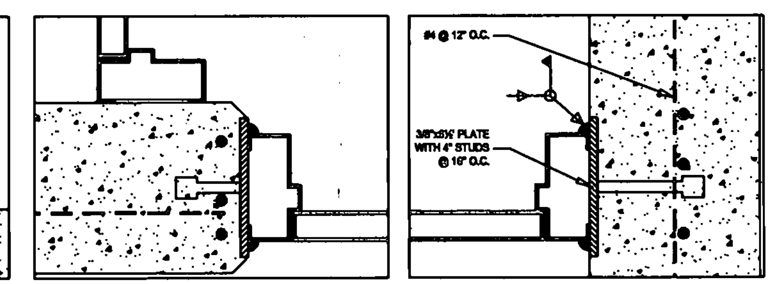
Ⓐ JAMB Ⓑ MULLION Ⓒ JAMB Ⓓ HEAD

205 DOUBLE DOOR ENTRY DETAILS
SCALE : 3" = 1'-0"



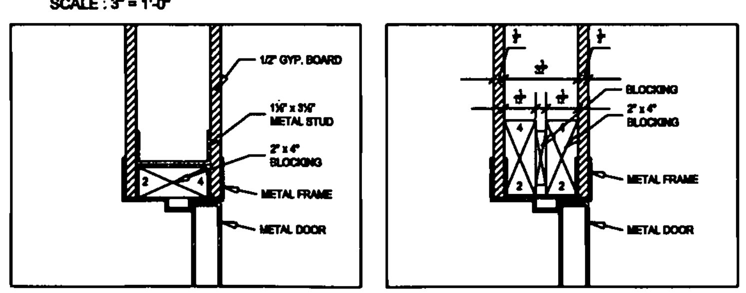
NOTE:
THRESHOLD IS LEVEL AT DOOR 6 & DOOR 2

206 THRESHOLD DETAIL
SCALE : 3" = 1'-0"



Ⓐ JAMB Ⓑ JAMB

207 JAMB DETAIL
SCALE : 3" = 1'-0"



Ⓐ JAMB Ⓑ HEAD

208 DETAILS AT DRYWALL
SCALE : 3" = 1'-0"

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

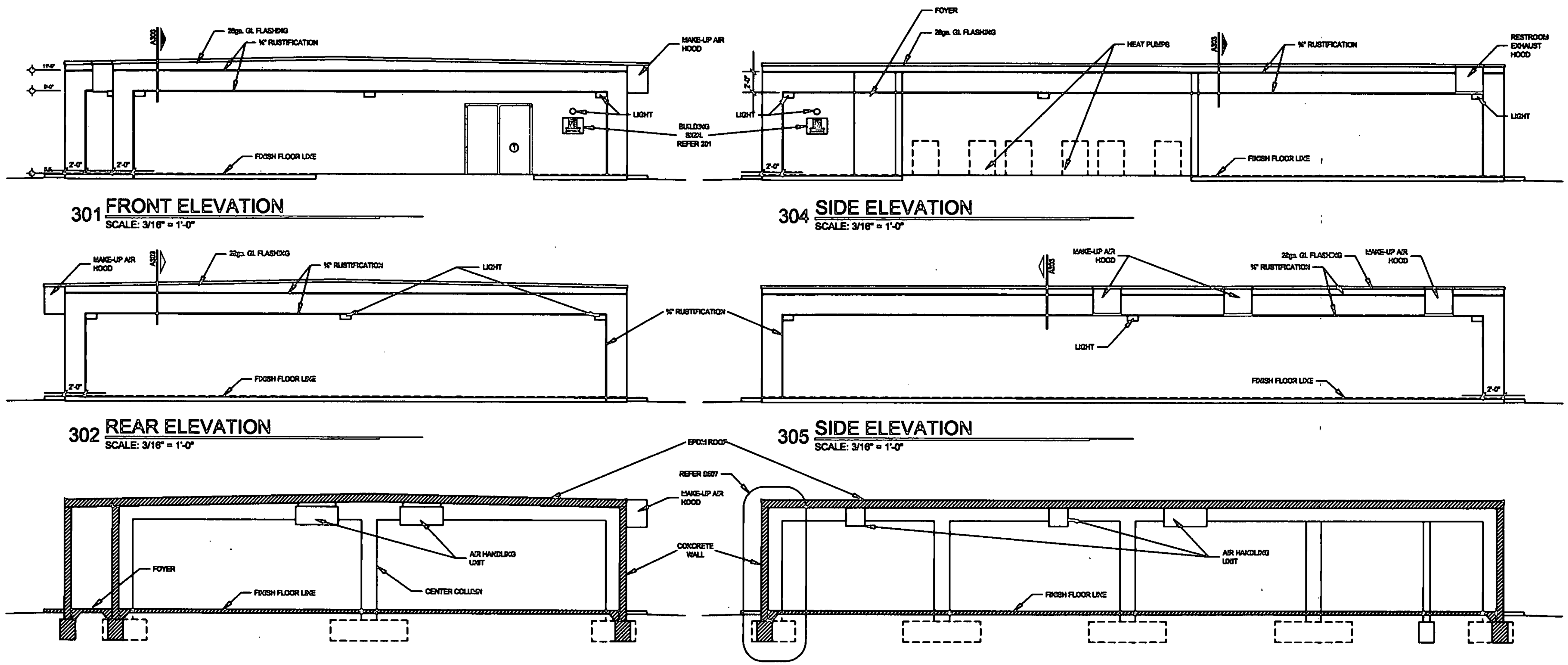
The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

SCHEDULES & DETAILS

SHEET No.: A2
DATE: 14 DECEMBER 1999
REVISED: | REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

BEST COPY AVAILABLE



301 FRONT ELEVATION
SCALE: 3/16" = 1'-0"

304 SIDE ELEVATION
SCALE: 3/16" = 1'-0"

302 REAR ELEVATION
SCALE: 3/16" = 1'-0"

305 SIDE ELEVATION
SCALE: 3/16" = 1'-0"

303 CROSS SECTION
SCALE: 3/16" = 1'-0"

306 CROSS SECTION
SCALE: 3/16" = 1'-0"

COMMUNITY SHELTER

HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

ELEVATIONS

SHEET No.: A3
DATE: 14 DECEMBER 1999
REVISED: | REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

BEST COPY AVAILABLE

BEST COPY AVAILABLE

GENERAL NOTES

1. NOTES AND DETAILS ON DRAWINGS SHALL TAKE PRECEDENCE OVER THESE GENERAL NOTES.

2. THE DESIGN ADEQUACY AND SAFETY OF ERECTION BRACING, SHORING, TEMPORARY SUPPORTS, ETC., IS THE SOLE RESPONSIBILITY OF THE CONTRACTOR, AND HAS NOT BEEN CONSIDERED BY THE STRUCTURAL ENGINEER. THE CONTRACTOR IS RESPONSIBLE FOR THE STABILITY OF THE STRUCTURE PRIOR TO THE APPLICATION OF ROOF DIAPHRAGMS AND FINISH MATERIALS. HE SHALL PROVIDE THE NECESSARY BRACING TO PROVIDE STABILITY PRIOR TO THE APPLICATION OF THE AFOREMENTIONED MATERIALS.

3. REFER TO PROJECT SPECIFICATIONS FOR MATERIAL SPECIFICATIONS AND PERFORMANCE REQUIREMENTS NOT COVERED BY THE STRUCTURAL DRAWINGS.

4. ALL DETAILS, SECTIONS AND NOTES SHOWN ON THE DRAWINGS ARE INTENDED TO BE TYPICAL AND SHALL APPLY TO SIMILAR CONDITIONS UNLESS OTHERWISE NOTED.

5. REFER TO DRAWINGS OF OTHER SECTIONS FOR ALL NON-STRUCTURAL INFORMATION INCLUDING EXACT LOCATION OF DOORS, WINDOWS, NONBEARING WALLS, PIPES, CONDUITS, DEPRESSIONS, DRAINS, INSULATION, FINISHES, ETC.

6. NO CONCRETE WORK SHALL BE PERFORMED DURING HEAVY RAIN, SNOW, OR HAIL, OR WHEN THE TEMPERATURE OF THE OUTSIDE AIR IS BELOW 40°F UNLESS APPROVED METHODS ARE USED TO PREVENT FREEZING OF CONCRETE. SUCH METHODS SHALL PREVENT THE MATERIALS FROM FREEZING FOR AT LEAST 48 HOURS. ALL MATERIALS USED AND MATERIALS BUILT UPON SHALL BE FREE FROM ICE AND SNOW. ALL MATERIALS ALLOWED TO FREEZE SHALL BE REMOVED AND REPLACED WITH NEW WORK ALL AT THE EXPENSE OF THE CONTRACTOR.

CONSTRUCTION JOINTS DESIGNATED TO HAVE ROUGHENED SURFACE SHALL BE PREPARED AS FOLLOWS: ALL OF THE CONSTRUCTION JOINT AREA EXCEPT 1" AROUND ALL EDGES SHALL BE ROUGHENED WITH A MIN. 1/8" WIDE x 1/8" DEEP GROOVE WITH A MINIMUM OF ½" CLEAR BETWEEN GROOVES. GROOVES SHALL BE MADE IN TWO DIRECTIONS THAT ARE AT RIGHT ANGLES TO EACH OTHER.

FOUNDATION NOTES

1. ALL FOOTINGS SHALL BE COMPLETELY FREE OF ANY LOOSE DIRT AND DEBRIS PRIOR TO PLACEMENT OF ANY CONCRETE.

2. ALL REINFORCING STEEL SHALL BE TIED AND SUPPORTED IN SUCH A MANNER TO INSURE THEY MAINTAIN THEIR PROPER LOCATION DURING THE PLACING OF THE CONCRETE. REINFORCING STEEL SHALL BE SUPPORTED ON APPROVED METAL CHAIRS OR BY SUSPENDING FROM ABOVE WITH ADEQUATE TIE WIRES DURING PLACEMENT OF CONCRETE. NO STEEL BARS DRIVEN INTO THE GROUND OR CONCRETE BRICKS WILL BE ALLOWED FOR SUPPORT OF THE REINFORCING STEEL.

3. THERE SHALL BE A VIBRATOR IN USE BY A QUALIFIED OPERATOR DURING THE PLACEMENT OF ALL CONCRETE. FAILURE TO USE A VIBRATOR BY A PERSON EXPERIENCED IN THE OPERATION THEREOF WILL BE CAUSE FOR REFUSAL TO ALLOW ANY CONCRETE PLACEMENT.

4. IF THE CONTRACTOR PLANS TO POUR THE GRADE BEAMS IN PHASES HE MUST SUBMIT A PLAN OF THE PHASES TO THE ENGINEER FOR APPROVAL PRIOR TO STARTING THE FOUNDATIONS. INCLUDED WITH THE PLAN SHALL BE DETAILS OF THE METHOD OF MAKING THE CONSTRUCTION JOINTS BETWEEN THE PHASES.

5. PROVIDE CORNER BARS IN BOTH FACES OF ALL GRADE BEAMS. NUMBER SIZE AND SPACING TO MATCH HORIZONTAL REINFORCEMENT WITH WHICH THEY LAP AND SHALL EXTEND 2'-6" IN EACH DIRECTION.

CONCRETE NOTES

1. CONCRETE FOR FOOTINGS, SIDEWALKS, FLOOR SLAB & PADS SHALL HAVE A MINIMUM COMPRESSIVE STRENGTH AT 28 DAYS OF 3000 PSI, A MINIMUM SLUMP OF 2" AND A MAXIMUM SLUMP OF 4"

2. CONCRETE FOR WALLS AND ROOF STRUCTURE SHALL HAVE A MINIMUM COMPRESSIVE STRENGTH AT 28 DAYS OF 4000 PSI, A MINIMUM SLUMP OF 2" AND A MAXIMUM SLUMP OF 4". CONCRETE SHALL HAVE AIR ENTRAINMENT OF 5% ±1%

3. CEMENT SHALL CONFORM TO A.S.T.M C-150M TYPE I.

4. ALL # 3 AND SMALLER REINFORCEMENT STEEL SHALL CONFORM TO A.S.T.M. A-615, GRADE 40 AND ALL #4 AND LARGER REINFORCEMENT STEEL SHALL CONFORM TO A.S.T.M. A-615, GRADE 60.

5. MINIMUM LAP FOR ALL REINFORCEMENT IS 30 BAR DIAMETERS BUT NOT LESS THAN 2'-0".

6. CONCRETE SHALL BE MIXED AND DELIVERED IN ACCORDANCE WITH A.S.T.M C-94.

7. BEFORE PLACEMENT OF CONCRETE, THE CONTRACTOR SHALL VERIFY PROPER PLACEMENT OF ALL ITEMS OF WORK WHICH ARE EMBEDDED IN THE CONCRETE.

8. THE CONCRETE WORK SHALL BE IN ACCORDANCE WITH ACI 318 AND 347.

9. CONCRETE FINISHES AND CURING SHALL CONFORM TO THE PROJECT SPECIFICATIONS.

10. REFER TO MECHANICAL, ELECTRICAL, ARCHITECTURAL, ETC. DRAWINGS FOR LOCATIONS OF ALL PIPES, CONDUITS, ETC.

11. THE STRENGTH LEVEL OF THE CONCRETE WILL BE CONSIDERED SATISFACTORY IF THE AVERAGE OF THE STRENGTH TESTS OF A GIVEN AREA OR PANEL EQUALS OR EXCEEDS THE SPECIFIED STRENGTH AT 28 DAYS, WITH NO INDIVIDUAL STRENGTH TEST OF SUCH AREA OR PANEL MORE THAN 5% BELOW THAT SPECIFIED. CONCRETE THAT DOES NOT MEET OR EXCEED THESE CRITERIA SHALL BE REMOVED BY THE CONTRACTOR AND BE REPLACED WITH CONCRETE, WHICH CONFORMS TO THESE CRITERIA, AT THE CONTRACTORS EXPENSE.

12. ALL CONCRETE CORNERS 10'-0" ABOVE F.F. ELEVATION SHALL BE ¾" CHAMFERED AT CORNERS, UNLESS OTHERWIZE NOTED ON PLANS. (DOES NOT APPLY TO CONCRETE FLOOR PLAN)

13. PROVIDE CORNER BARS IN CENTER OF ALL WALLS. NUMBER SIDE AND SPACING TO MATCH HORIZONTAL REINFORCEMENT WITH WHICH THEY LAP AND SHALL EXTEND 2'-6" IN EACH DIRECTION.

DESIGN SPECIFICATIONS

ACI 318-95 (ALTERNATE DESIGN METHOD)
ASCE 7-98 (MINIMUM DESIGN LOADS)

FOUNDATION PRESSURE

ASSUMED BEARING ALLOWABLE OF 2100 PSF.
CONTRACTOR SHALL FURNISH SOIL REPORT AS PER SPECIFICATION

DESIGN LOADS:

WIND LOAD : 200 MPH (3 SECOND PEAK GUST @ 33') EXPOSURE "C", I=1.15
IMPACT LOAD : BASED ON A 15lb MISSILE (A NOMINAL 2"x4" WOOD MEMBER) TRAVELLING HORIZONTALLY AT 100 MPH OR VERTICALLY AT 67 MPH AND IMPACTING THE SURFACE @ 90°

ROOFING COLLATERAL ROOF D.L. : 6 psf
ROOF L.L. : 20 psf

COMMUNITY SHELTER

HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

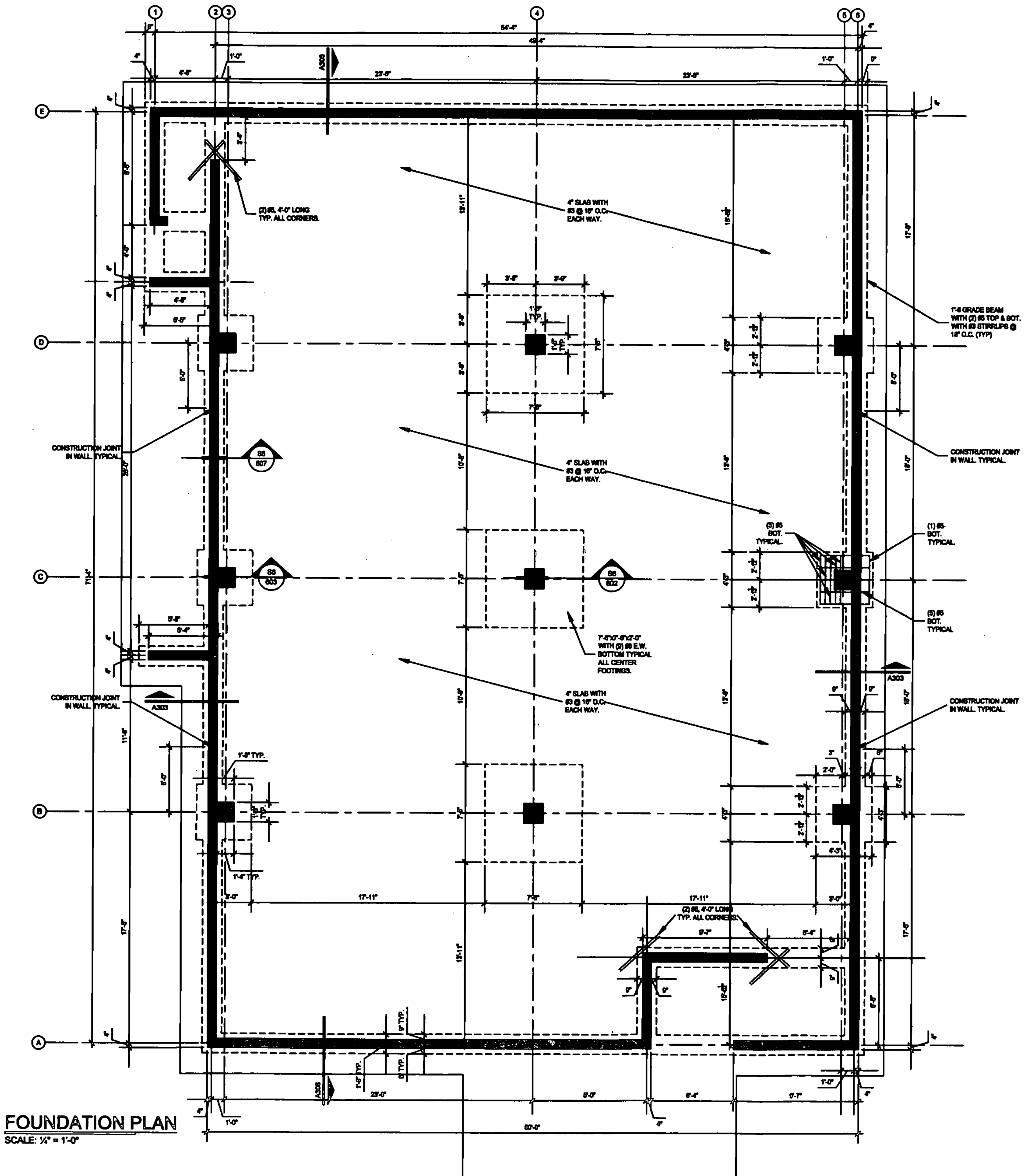
Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

STRUCTURAL NOTES

SHEET No.: S1	
DATE: 14 DECEMBER 1999	
REVISED:	REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC



S201 **FOUNDATION PLAN**
SCALE: 1/4" = 1'-0"

COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

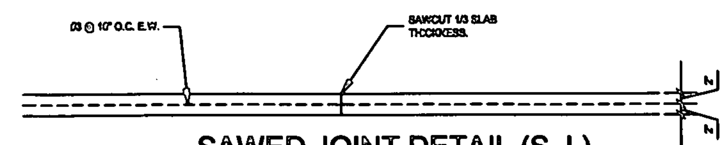
The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

FOUNDATION PLAN

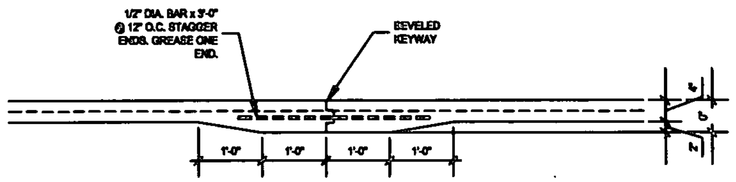
SHEET No.: S2
DATE: 14 DECEMBER 1999
REVISED: | REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

BEST COPY AVAILABLE



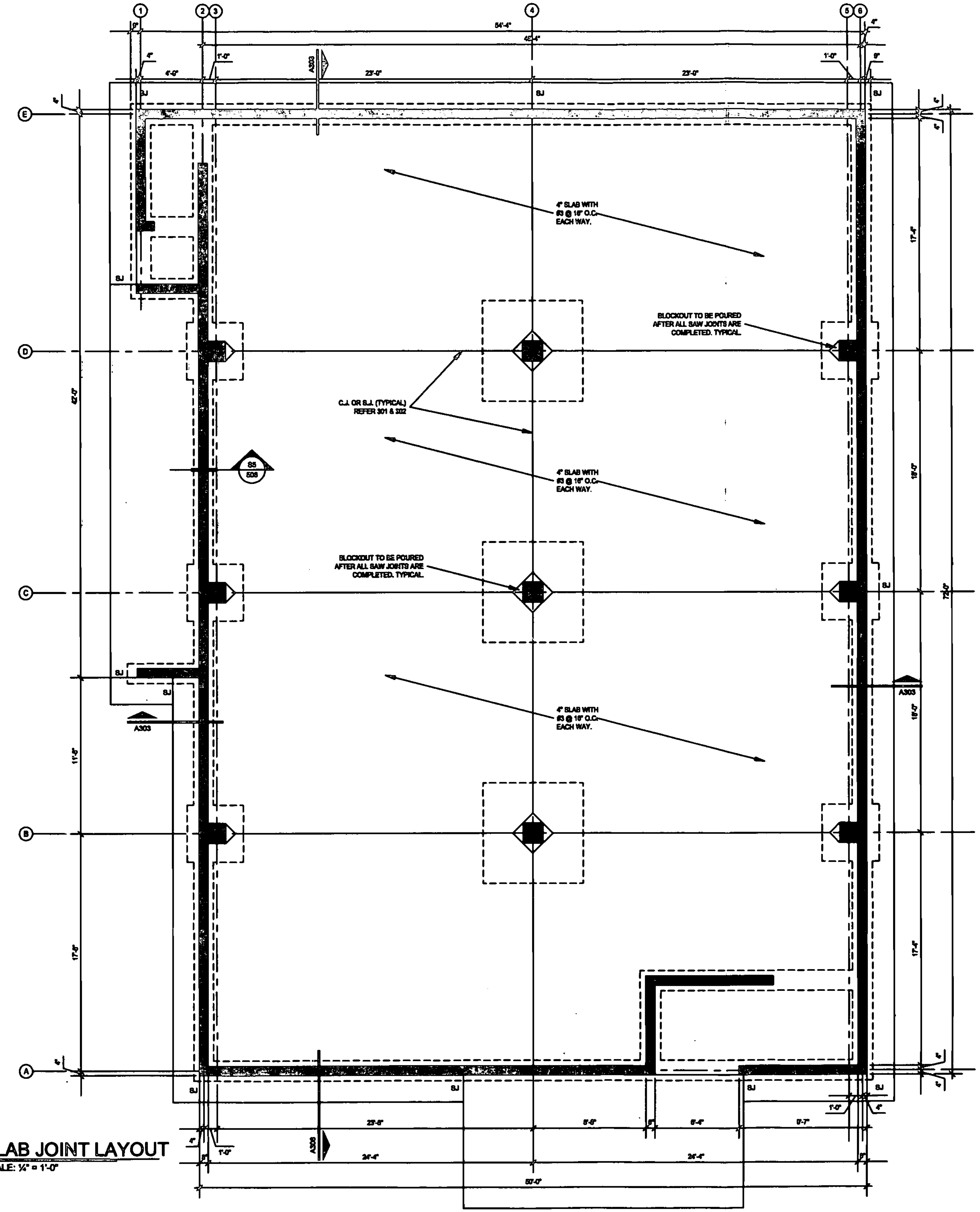
S301 SAWED JOINT DETAIL (S.J.)
SCALE: ¾" = 1'-0"



S302 CONSTRUCTION JOINT DETAIL (C.J.)
SCALE: ¾" = 1'-0"

SLAB JOINT NOTES:

1. BLOCKOUT AROUND ALL COLUMNS AND PILASTERS.
2. CONTRACTOR MAY USE EITHER CONSTRUCTION JOINT OR SAWED JOINTS AT LOCATIONS SHOWN.
3. FILL ALL BLOCKOUTS WITH 3000 PSI CONCRETE AFTER ALL THE SLAB HAS BEEN PLACED AND ALL SAWING HAS BEEN COMPLETED.



S303 SLAB JOINT LAYOUT
SCALE: ¼" = 1'-0"

221

BEST COPY AVAILABLE

COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

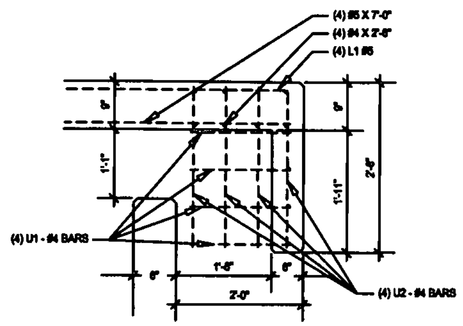
The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

SLAB JOINT LAYOUT

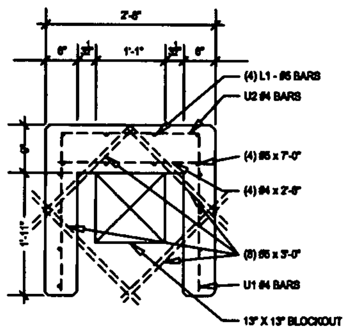
SHEET No.: S3	
DATE: 14 DECEMBER 1999	
REVISED:	REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

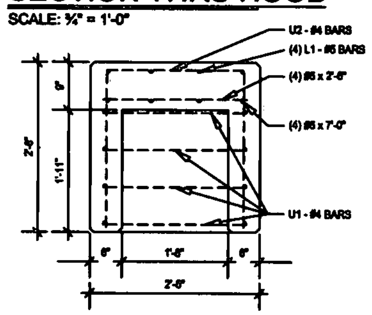
222



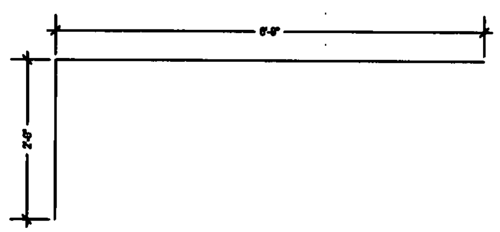
S401 SECTION THRU HOOD
SCALE: ¾" = 1'-0"



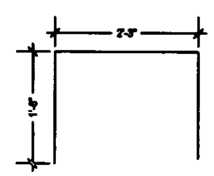
S402 SECTION THRU HOOD
SCALE: ¾" = 1'-0"



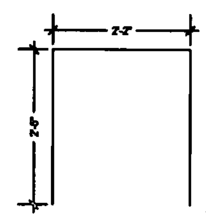
S403 SECTION AT HOOD
SCALE: ¾" = 1'-0"



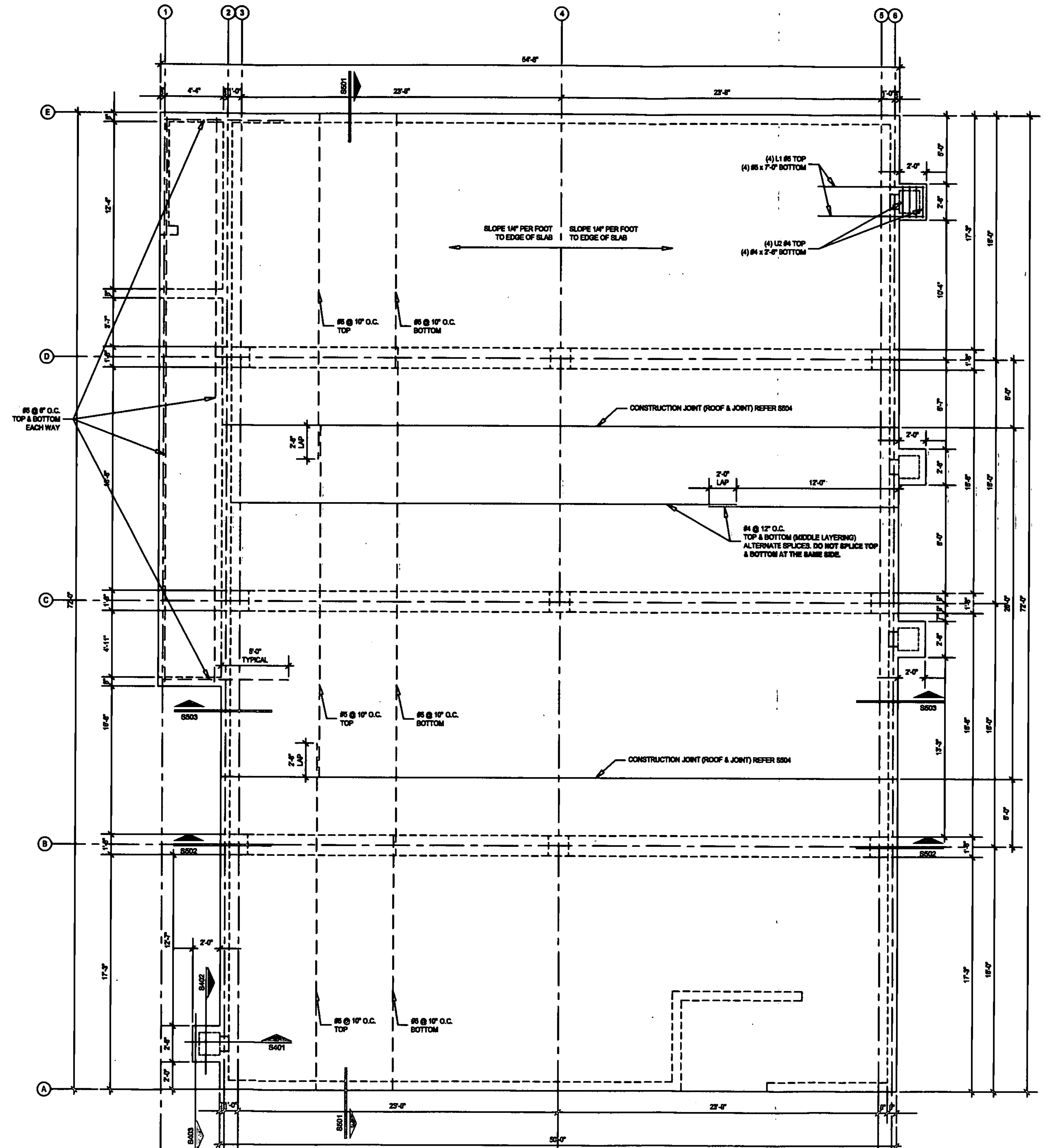
S404 L1 #5 BAR x 9'-3"
SCALE: ¾" = 1'-0"



S405 U1-#4 BARS x 5'9"
SCALE: ¾" = 1'-0"



S405 U2-#4 BARS x 7'0"
SCALE: ¾" = 1'-0"



S406 ROOF REINFORCING PLAN
SCALE: ¼" = 1'-0"

BEST COPY AVAILABLE

COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

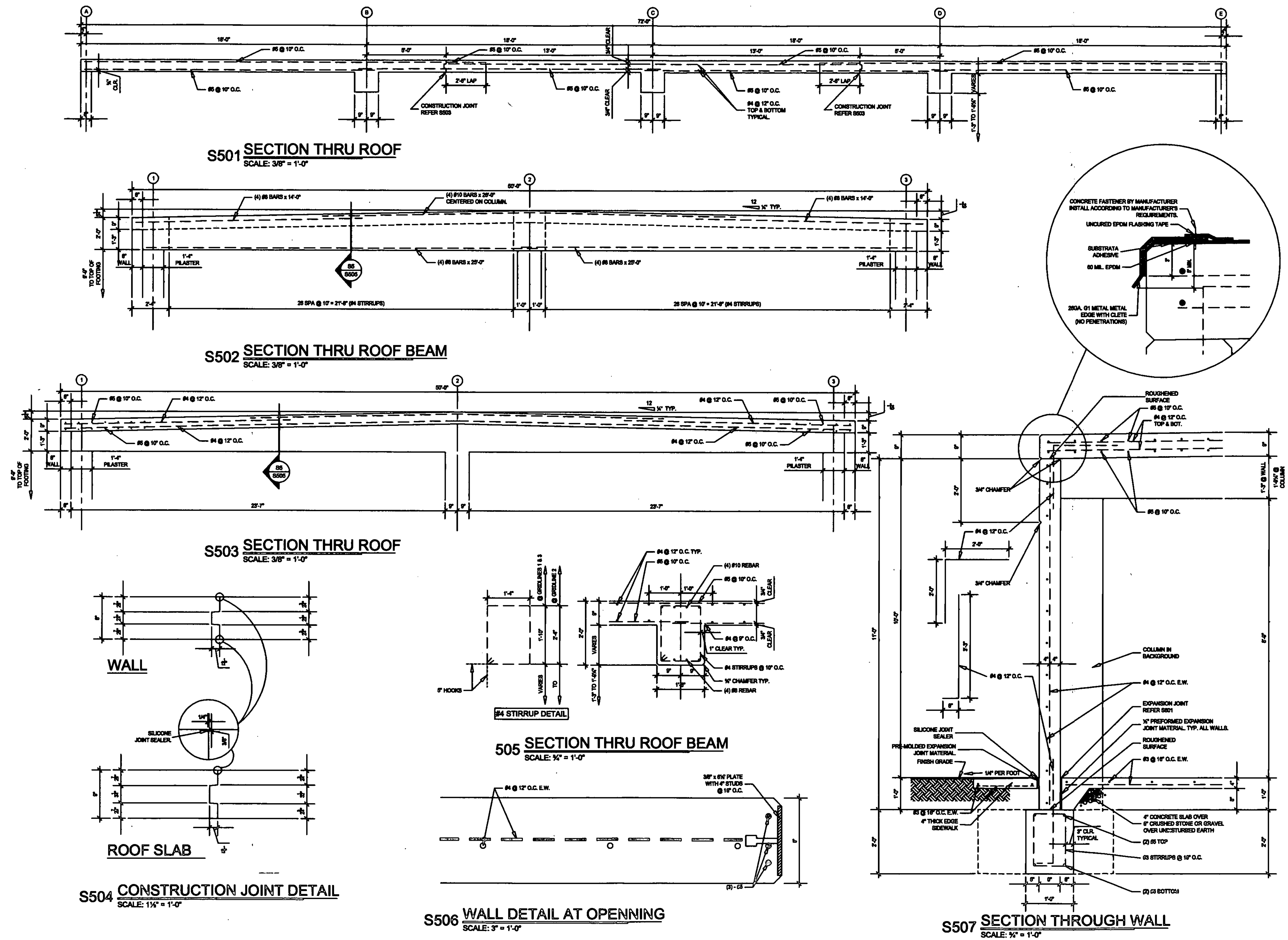
ROOF REINFORCING PLAN

SHEET No.: S4
DATE: 14 DECEMBER 1999
REVISED: | REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

223

224



COMMUNITY SHELTER

HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

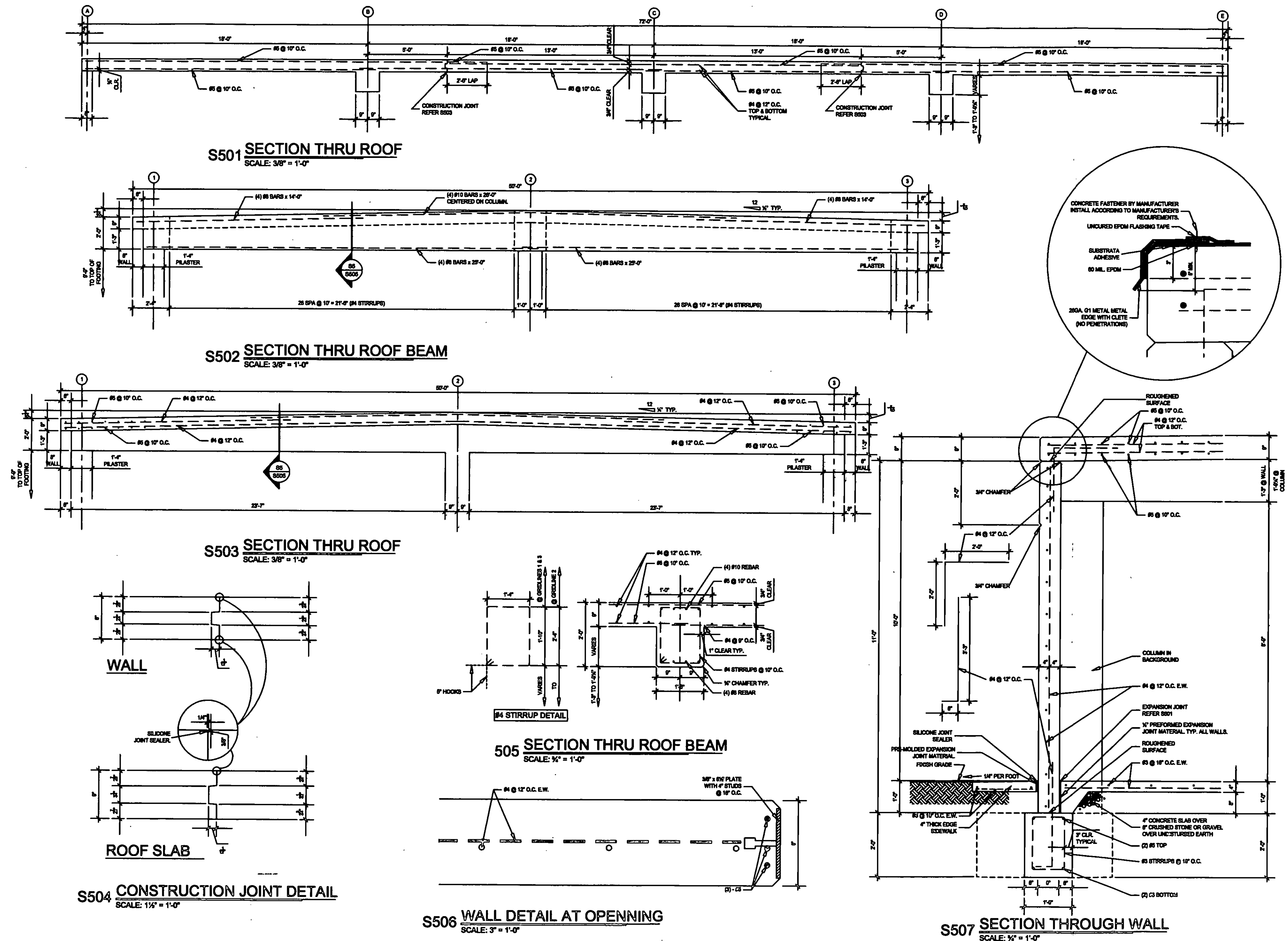
The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

STRUCTURAL DETAILS

SHEET No.: S5	
DATE: 14 DECEMBER 1999	
REVISED:	REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

BEST COPY AVAILABLE



227

COMMUNITY SHELTER

HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

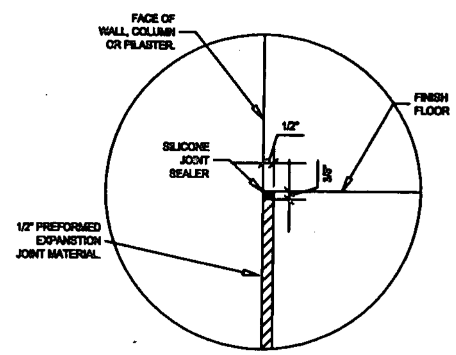
STRUCTURAL DETAILS

SHEET No.: S5
DATE: 14 DECEMBER 1999
REVISED: | REV. NO.

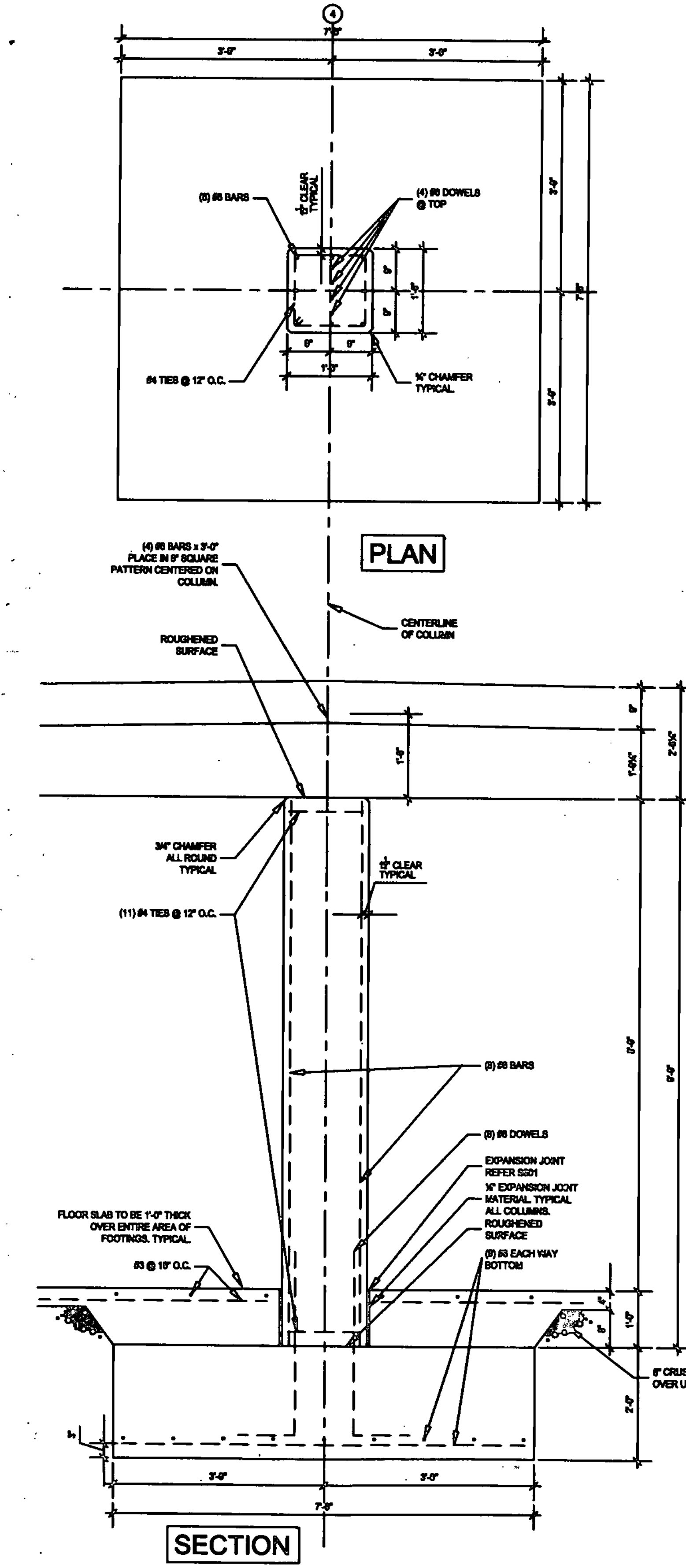
FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

BEST COPY AVAILABLE

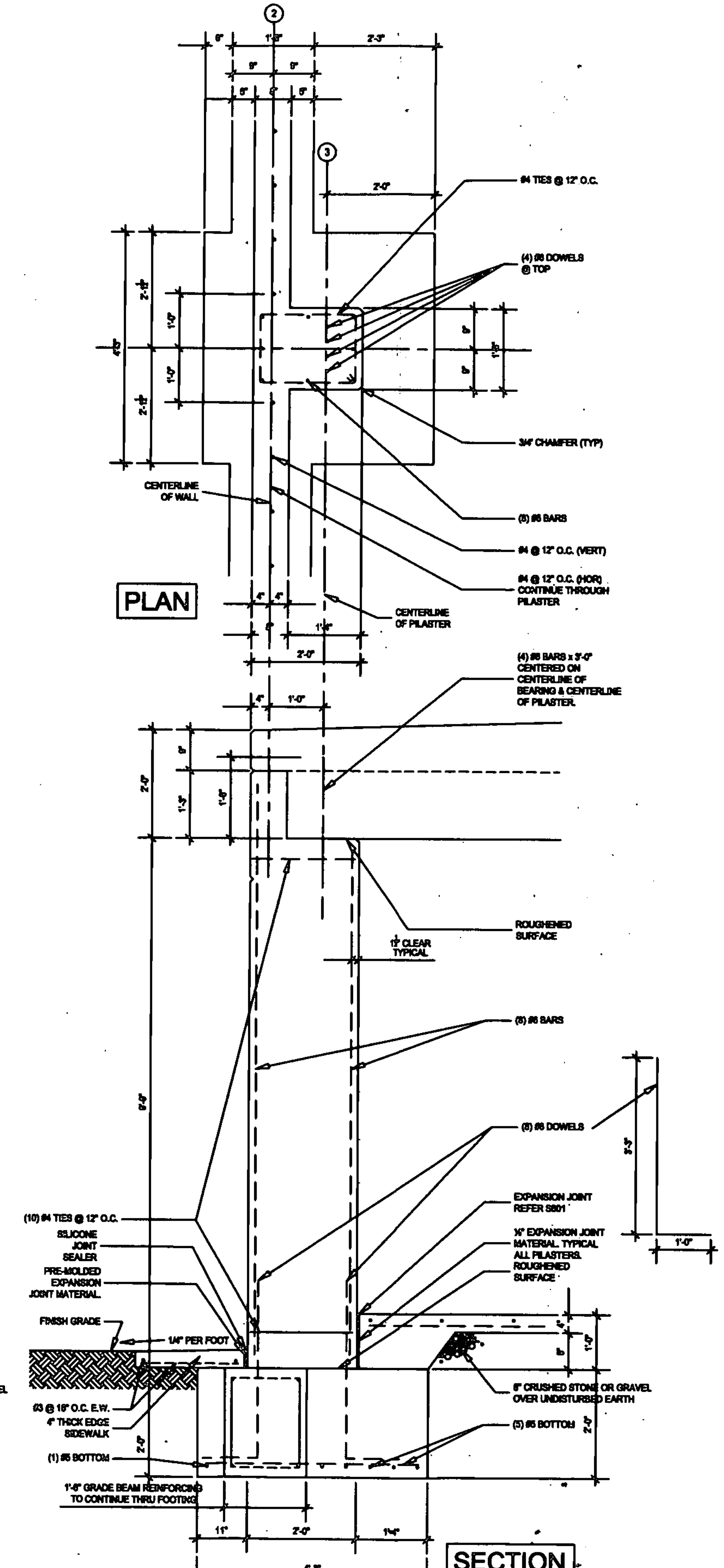
228



S601 SEALANT DETAIL
SCALE: 3" = 1'-0"



S602 DETAILS THRU CENTER COLUMN
SCALE: ¾" = 1'-0"



S603 DETAILS THRU PILASTER
SCALE: ¾" = 1'-0"

COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

STRUCTURAL DETAILS

SHEET No.: S6
DATE: 14 DECEMBER 1999
REVISED: REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

Heating & Cooling Load Calculations:
BASED ON RALEIGH NORTH CAROLINA LOCATION

Heat Loss- 246,341 BTUH
Heat Gain- 259,057 BTUH

Equipment Schedule- Carrier- Electric Air Handler & Heat Pump

6- Air Handlers- FC4BNF048- 1700 CFM- 208-230/60/1- 3/4 H.P.- 4.3 FLA- Factory installed TXV metering device
Length- 49 5/8", Width- 22 1/16", Height- 21 1/8"
Weight- 150 Lbs.

6- Auxiliary Heat Strips- KFAEH0401N10- 10 KW@- 31,400 BTUH@
Fuse Size- 60 Amps.

6- Heat Pumps-38YCC048301- 46,000 BTUH Cooling@- 10.00 SEER- 208-230/60/1
47,000 BTUH@47 Degree DB- 3.20 COP- 7.20 HSPF
29,600 BTUH@13 Degree DB- 2.24 COP
Compressor- 24.4 RLA- MCA- 31.9 Amps.- Max. Fuse Size- 50 Amps.- Condenser Fan- 1/4 H.P.- 1.4 FLA
Width- 29 1/8", Depth- 29 9/16", Height- 39 15/16"
Weight-219 Lbs.

6-Thermostats- TSTATCCNHP01-A- Auto Changeover, Non-Programmable, 2 Stage Heat-1 Stage Cool- Auto/Manual Fan

6- Start Assist- KSAHS1601AAA
6- Outdoor Thermostats- KHAOT0301FST

Refrigeration Lines

From each air handler coil, install properly sized refrigeration lines to heat pumps. Secure refrigeration lines to concrete ceiling with proper fasteners.

Condensate Drains.

From air handlers hanging close together, bring 3/4" PVC from each and tee together. Run 3/4" PVC across and out thru wall.

SUPPLY AIR

Each horizontal air handler will have short 12" supply plenum on supply side of unit. Will install one supply diffuser on front to supply air to areas. On one unit near office, will install starting collar with air scoop. Will run 8" sheetmetal duct from plenum to supply box at office wall. Will elbow below concrete beam to high sidewall supply box. Duct will be secured to concrete ceiling with proper fasteners.

Return Air

Each horizontal air handler will have short 12" return air plenum on return air end of unit. Will install filter rack inside of return air so that filter can be easily changed.

Ventilation Air (885 CFM Fresh Air)

Each horizontal air handler will have 8" round sheetmetal fresh air duct coming off of return air plenum. Each 8" duct will run into 10" x 8" x 8" tee. 10" round sheetmetal duct will then be ran to wall mounted filter box at wall. This box will have 12" x 12" metal filter in box. On outside of wall there will be 12" x 12" Louvered Grille. All duct will be secured to concrete ceiling with proper fasteners.
Install manual damper in 10" duct near filter box.

Air Devices AirMate

Supply Diffusers

20" X 18"- #220-V- Multi-Shutter Damper - White
14" X 6"- #220-V- Multi-Shutter Damper - White

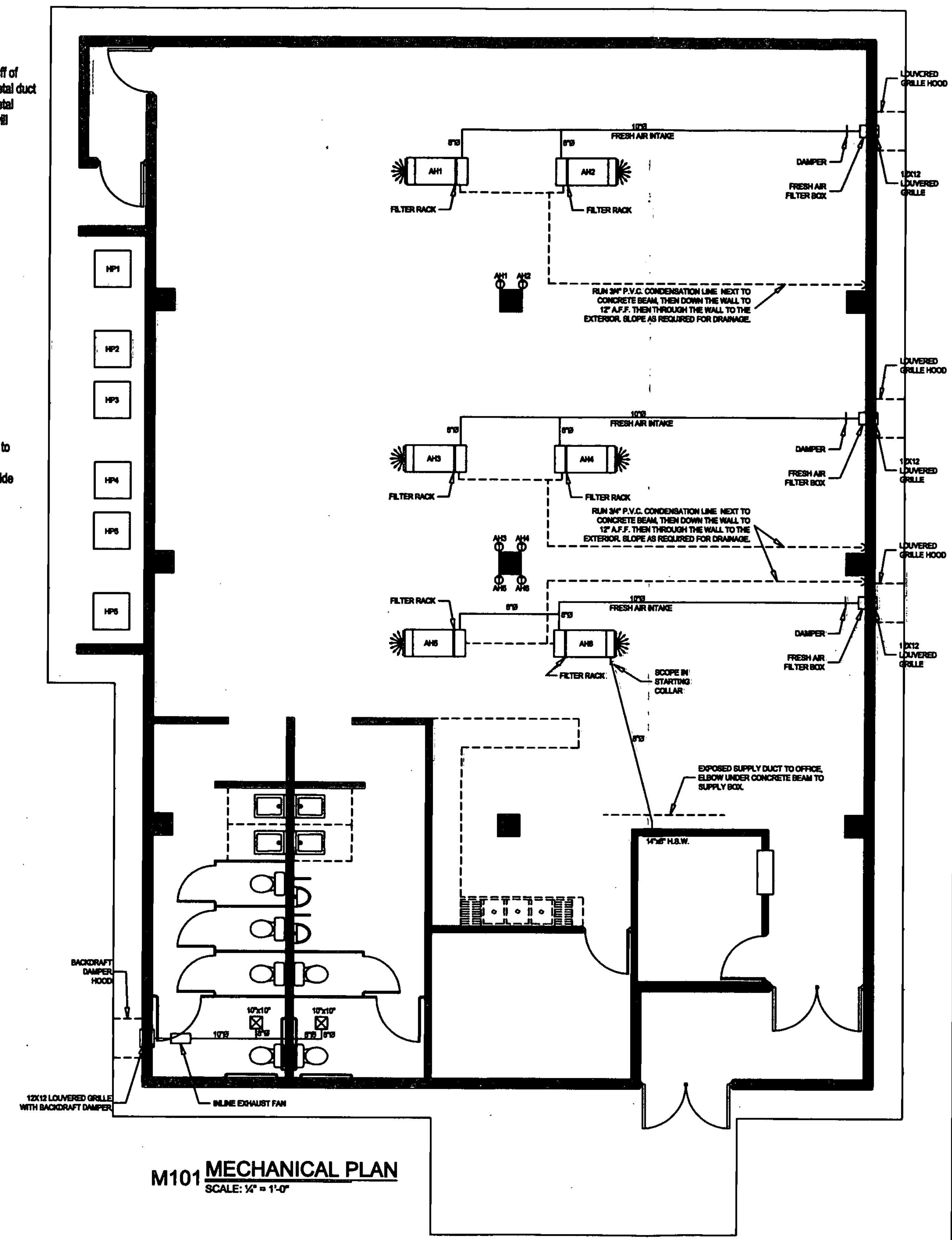
Return Air

None- Open return plenums with filter rack inside.

Exhaust Fan Tjernlund

1- #EF-10- 10" In-line exhaust fan. 115/60/1- 0.46 Amps.- 10" Duct connection.
Width- 15 1/2", Diam.- 10", Weight- 10 Lbs.

Attach 10" x 10" exhaust air box in each restroom. Run 8" sheetmetal from each to sheetmetal tee, then run 10" duct to inline exhaust fan. From fan, run 10" duct to 12" x 12" wall box. Mount 12" x 12" Louvered Grille W/Backdraft damper on outside of wall. Secure duct to concrete ceiling with proper fasteners.



M101 MECHANICAL PLAN
SCALE: 1/4" = 1'-0"

COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

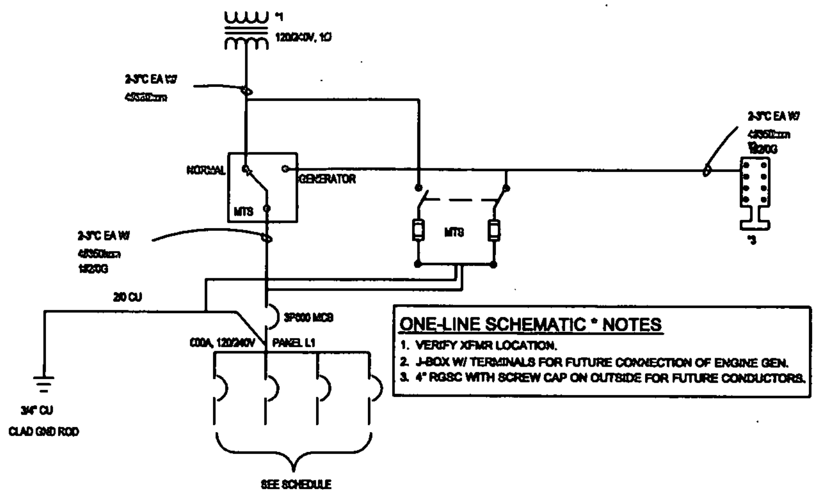
Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

MECHANICAL PLAN

SHEET No.: M1
DATE: 14 DECEMBER 1999
REVISED: REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC



ONE-LINE SCHEMATIC * NOTES
1. VERIFY XFMR LOCATION.
2. J-BOX W/ TERMINALS FOR FUTURE CONNECTION OF ENGINE GEN.
3. 4" RGSC WITH SCREW CAP ON OUTSIDE FOR FUTURE CONDUCTORS.

E101 ONE LINE SCHEMATIC

ELECTRICAL SPECIFICATIONS

1. SECTION 16010 - BASIC ELECTRICAL REQUIREMENTS

A. All material shall be UL approved where standards are established.

B. Materials and equipment shall be of current production by recognized manufacturers with spare parts available. All units of the same class shall be of the same manufacturer.

C. Materials shall be installed as indicated and meet requirements of the NFPA, including NEC.

2. SECTION 16110 - RACEWAYS

A. Install according to NEC. Minimum size to be 1/2". Provide a complete assembly with all fittings and accessories.

B. All conduit shall be surface mounted. No imbedded conduit.

C. EMT for all other interior applications. EMT couplings and connectors shall be compression type. Rigid galvanized steel conduit for all outside conduit. Sealtight for connection to motors.

D. Seal all fire wall penetrations with fire retardant silicone foam, CTC PR-855, Chase Technology.

3. SECTION 16120 - WIRE, CABLE AND CONNECTORS

A. Wire and Cable

1. Copper conductors.

2. Minimum size No. 12 AWG, No. 8 and larger shall be stranded.

3. Insulation shall be type THHN/THWN.

B. Connectors

1. No. 10 AWG and smaller, solderless, screw-on pressure type.

2. Larger than No. 10 AWG bolt clamp-type.

3. 250 kcm or larger shall have at least two clamping elements.

C. Control Wiring

1. No. 18 AWG minimum.

2. Refer to Division 15 for control wiring of mechanical equipment.

D. Signal Wiring as recommended by system manufacturer.

4. SECTION 16135 - ELECTRICAL BOXES AND FITTINGS

Interior boxes shall be sheet steel with knockouts. Exterior boxes shall be gasketed cast metal.

5. SECTION 16143 - WIRING DEVICES

A. Receptacles shall be 15 ampere, 125 volt AC, duplex. NEMA 15-5R.

B. Switches shall be rated 20 amperes at 277 volts AC.

C. All switches and receptacles shall be quiet-type, specification grade.

D. Device plates shall be stainless steel in finished areas and zinc coated steel for unfinished areas.

E. Photo electric control cell shall be rated 3000W, similar and equal to Tork #35403.

6. SECTION 16441 - ENCLOSED SWITCHES

A. Disconnect switches shall be fusible, NEMA KS 1, Type GD load break.

B. Enclosures: NEMA KS1. Interior dry locations; Type 1, Exterior locations; Type 3R.

C. Neutral and ground buses required.

D. Manual transfer switch shall be Double throw type similar and equal to Cutler Cutler Hammer #DT326FGK in NEMA1 enclosure.

E. Fuses:

Fuses protecting motors or transformers shall be Bussmann type FRN-R. Fuses for MTS to be Type T.

7. SECTION 16470 - PANELBOARDS

A. Circuit breaker type for branch ckt. Lighting and Power equal to GE, Square D or Cutler Hammer, complete with protective devices and accessories as required.

B. Shall be dead-front safety type, enclosed in a sheet steel cabinet.

C. Neutral and ground buses required.

D. Molded case circuit breakers shall meet NEMA and UL standards.

1. Breakers shall be one, two, or three-pole units as indicated and shall operate both manually and automatically.

2. All poles shall operate simultaneously and mechanism shall be trip free

3. Minimum interrupting capacity shall be 14,000 amps at 120/208 volts and 22,000 amps at 277/480 volts.

8. SECTION 16452 - GROUNDING

A. Ground buses and neutral buses shall be isolated except in main switchgear and transformer terminal compartments.

B. All branch and feeder circuits shall include green grounding conductors.

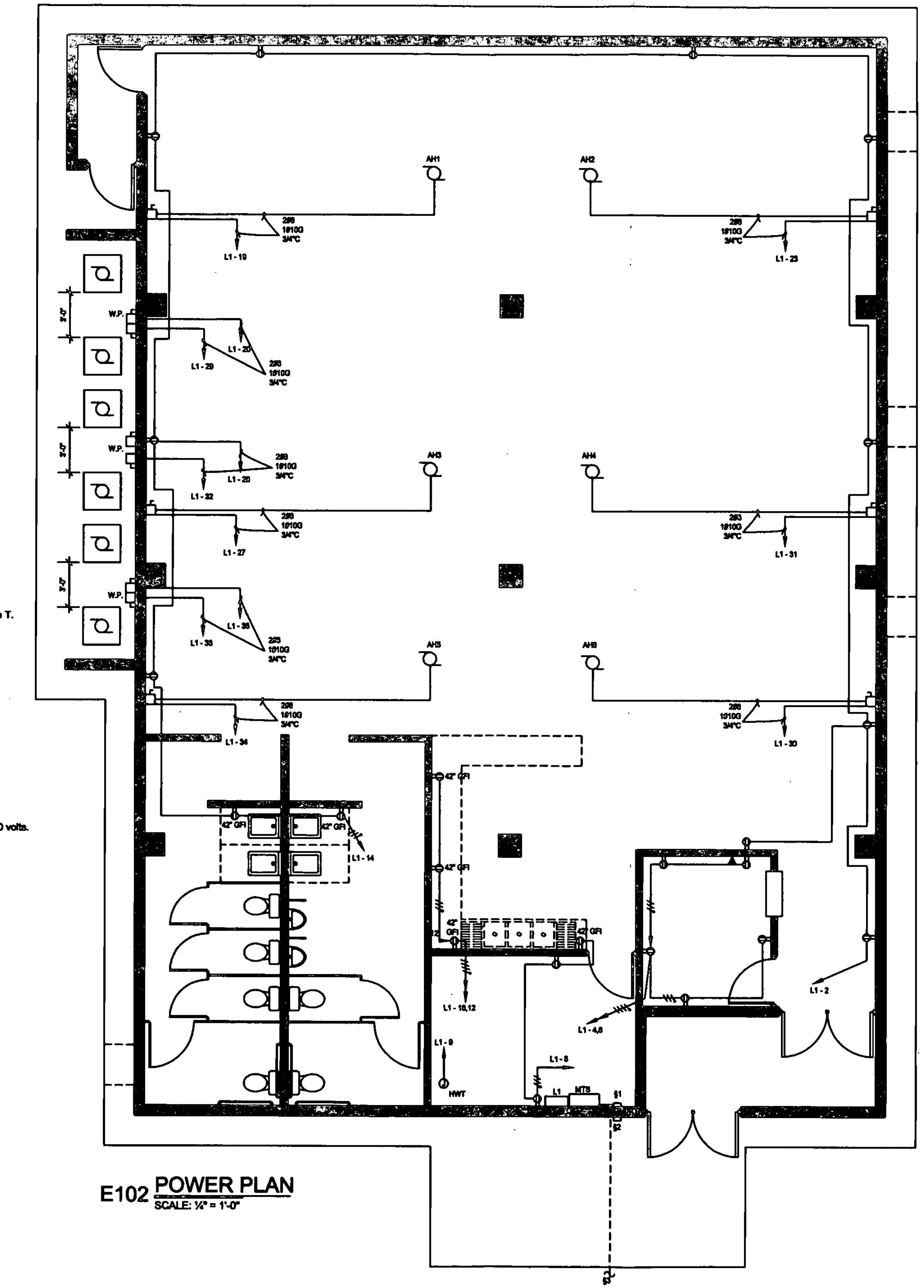
9. SECTION 16515 - INTERIOR LIGHTING FIXTURES AND ACCESSORIES
Furnish as scheduled.

10. SECTION 16722 - FIRE ALARM SYSTEM

A. Shall be self contained, 120V, similar and equal to BRK #1839W1-2.

B. Comply with all local Codes.

POWER PLAN NOTES
§1. JUNCTION BOX WITH TERMINALS FOR FUTURE CONNECTION.
§2. RGSC STUBED THROUGH WALL WITH SCREW CAP.
§3. UNDERGROUND SERVICE FEEDER TO SERVICE TRANSFORMER.



E102 POWER PLAN
SCALE: 1/4" = 1'-0"

COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:
The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

POWER PLAN

SHEET No.: E1	
DATE: 14 DECEMBER 1999	
REVISED:	REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

BEST COPY AVAILABLE

ELECTRICAL SYMBOLS

SYMBOL	DESCRIPTION
	FLUORESCENT LIGHTING FIXTURE, TYPE No. INDICATED
	INCANDESCENT LIGHTING FIXTURE, CEILING OR WALL MOUNTED
	EXIT LIGHTING FIXTURE, CEILING OR WALL MOUNTED
	EXIT LIGHTING FIXTURE WITH EMERGENCY LIGHTS
	JUNCTION BOX
	JUNCTION BOX FOR FUTURE SPEAKER
	UTILITY OUTLET BOX, SEE DETAIL
	DUPLEX RECEPTACLE
	DUPLEX RECEPT MNT'D IN HORZ POSITION, 6" ABOVE COUNTER
	DOUBLE DUPLEX RECEPTACLE
	SIMPLEX RECEPTACLE WITH DEDICATED CKT
	POLARIZED RECEPTACLE, STYLE AS NOTED
	COMPUTER RECEPTACLE, WALL OR FLOOR BOX
	LOW VOLTAGE RELAY
	SWITCH AND RECEPTACLE, MOUNTED IN SINGLE OUTLET BOX
	MASTER CLOCK
	SECONDARY CLOCK
	CLOCK OUTLET
	DOUBLE FACE CLOCK
	FLOOR BOX WITH DOUBLE DUPLEX RECEPTACLE
	FLOOR BOX WITH RECEPTACLE OUTLET
	FLOOR BOX WITH TELEPHONE OUTLET
	MICROPHONE OUTLET
TV	TELEVISION OUTLET
	INTERCOM OUTLET
	"PHONO" OUTLET FLOOR MOUNTED
	"PHONO" OUTLET WALL MOUNTED
	SPEAKER
	SOUND SYSTEM VOLUME CONTROL
	TELEPHONE OUTLET, 12" AFF
	TELEPHONE OUTLET MNT'D IN HORZ POSITION 6" ABOVE COUNTER
	TELEPHONE OUTLET MNT'D AT 42" AFF
	SPECIAL CONDITIONS, SEE DETAIL
	KITCHEN ITEMS, SEE KITCHEN PLANS FOR DESCRIPTION
*1,*2,*3	SEE NOTES
	THERMOSTAT
	AQUASTAT
	TRANSFORMER
	FIRE ALARM VISUAL INDICATOR ONLY
	FIRE ALARM PULL STATION
	FIRE ALARM AUDIBLE-VISUAL INDICATOR
	FIRE ALARM HORN
	FIRE ALARM BELL
	FIRE ALARM SMOKE DETECTOR
	FIRE ALARM HEAT DETECTOR
	FIRE ALARM FLAME DETECTOR
	FIRE ALARM DUCT DETECTOR
	SINGLE POLE WALL SWITCH
	TWO POLE WALL SWITCH
	THREE-WAY WALL SWITCH
	FOUR-WAY WALL SWITCH
	SINGLE POLE WALL SWITCH WITH PILOT LIGHT
	SINGLE POLE WALL SWITCH, KEY OPERATED
	SINGLE POLE WALL SWITCH, LOW VOLTAGE
	PLUG IN STRIP
	MANUAL MOTOR STARTER, SINGLE PHASE
	MOTOR DISCONNECT SWITCH
	MAGNETIC MOTOR STARTER
	MAGNETIC CONTACTOR
	COMBINATION MOTOR DISCONNECT SWITCH
	MOTOR WITH HORSEPOWER RATING
	ELECTRIC PANEL
	TELEPHONE TERMINAL CABINET
	TELEPHONE TERMINAL BOARD
	CIRCUIT HOME RUN, TWO WIRES & GREEN GROUND INDICATED
	CONDUIT EXPOSED ON WALL OR AT CEILING
WP	DENOTES WEATHERPROOF
(E)	DENOTES EXISTING TO BE RETAINED
EDF	ELECTRIC DRINKING FOUNTAIN
EG	EQUIPMENT GROUND
MD	MOTION DETECTOR
PC	PART CIRCUIT
GFCI	GROUND FAULT CIRCUIT INTERRUPTER
	NOTE: NOT ALL SYMBOLS USED

LIGHTING FIXTURE SCHEDULE

FIXT. I.D.	TYPE	MANUFACTURER & CATALOG NUMBER	LAMPS NO.	LAMPS WATTS	LAMPS TYPE	REMARKS MOUNTING
A	STRIP	LITHONIA #UN432120GEB	4	32	F32T8/SP35	SURFACE *1
B	STRIP	LITHONIA #UN232120GEB	2	32	F32T8/SP35	SURFACE
C	EMERGENCY LT	LITHONIA #ELT125SSBH1212	2	12	FURNISHED	WALL SURFACE @ 8'AFF
D	WALL PACK	LITHONIA #TWH175M120LPI	1	175	175MVR175/U	WALL SURFACE @ 10' AFF
E	SIGN LT	GE #SSN03MOH	1	35	MH35/U	*2
X	EXIT	LITHONIA #LESB1R120ELN	-	-	FURNISHED	SURFACE ABOVE DOOR

LIGHTING FIX NOTES: *1 FURNISH W/ 2 BALLASTS FOR INSIDE & OUTER LAMPS.
*2 MOUNT JUST ABOVE SIGN. USE RGSC TO EXTEND FIX 24" FROM WALL. AIM FIX TOWARD SIGN.

PANEL L1, SINGLE Ø, 3 WIRE, 120/240 V, 600 A MCB.

14,000 RMS SYM. A.I.C., ENCLOSURE: NEMA 1, MOUNTING: ELECT/MECH ROOM.

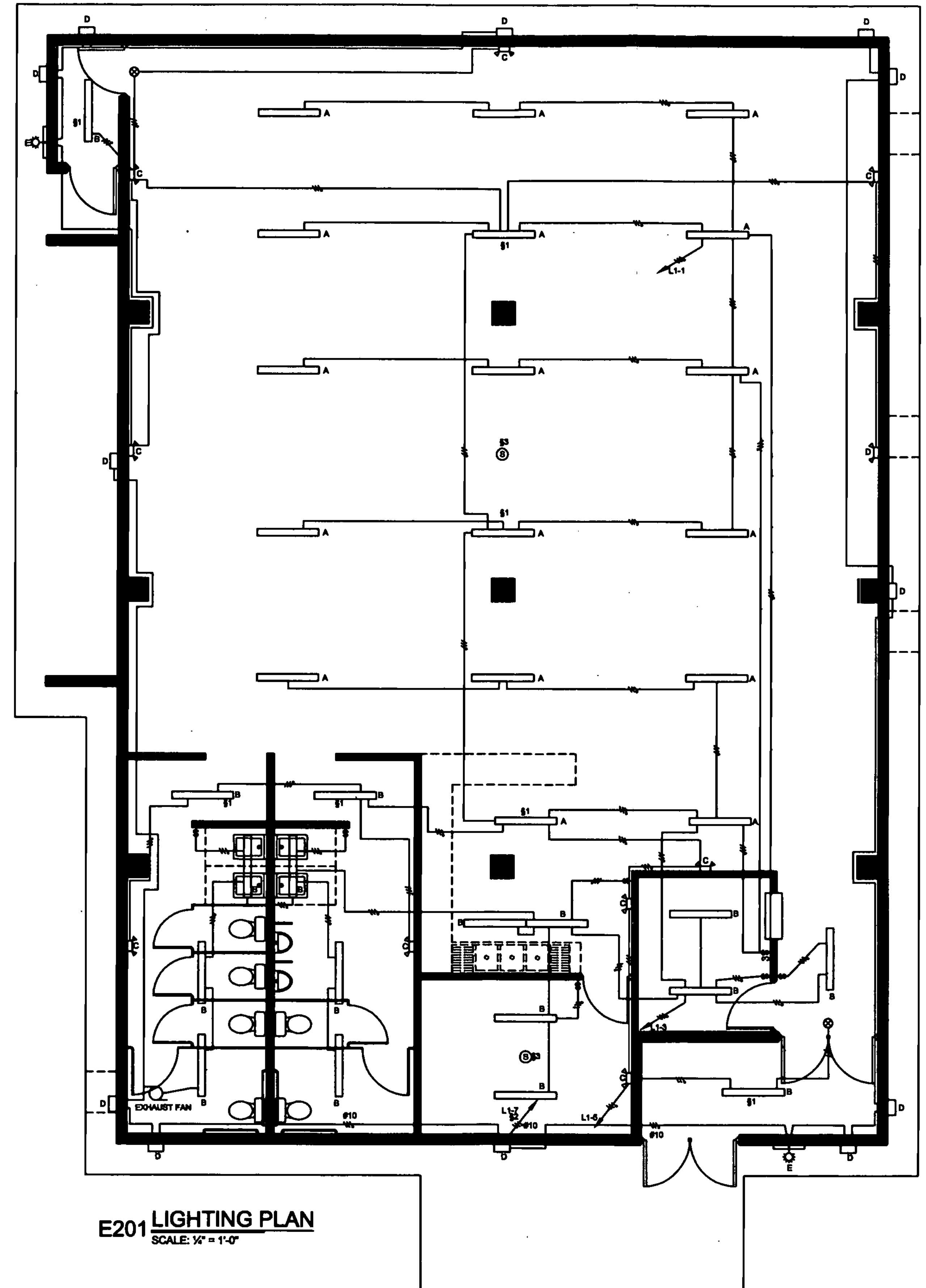
MLO-MAIN LUGS ONLY, MCB-MAIN CIRCUIT BREAKER, MCS-MOLDED CASE SWITCH, HCAR-AIR CONDITIONING BREAKER.

CIRCUIT USE	CCT. BKR.	NO.	CONNECTED LOAD VA ØA	CONNECTED LOAD VA ØC	NO.	CCT. BKR.	CIRCUIT USE
BACK LTS	1P20	1	1650			1P20	RECPT
			1200		2		
FRONT LTS	1P20	3		1750		1P20	RECPT OFFICE
				600	4		
EMG LTS	1P20	5	660			1P20	RECPT OFFICE
			600		6		
OUTSIDE LTS	1P20	7		2860		1P20	RECPT MECH RM
				600	8		
HOT WATER TANK	2P30	9	1200			1P20	RECPT KIT
			200		10		
HOT WATER TANK	2P30	11		1200		1P20	RECPT KIT
				400	12		
SPACE	–	13	–			1P20	RECPT
			1200		14		
SPACE	–	15		–		1P20	SPARE
				–	16		
SPACE	–	17	–			1P20	SPARE
			–		18		
AH1	2P60	19		5500		2P60	HP1 (HACR)
				2950	20		
-- --	--	21	5500			--	-- --
			2950		22		
AH2	2P60	23		5500		2P60	HP2 (HACR)
				2950	24		
-- --	--	25	5500			--	-- --
			2950		26		
AH3	2P60	27		5500		2P60	HP3 (HACR)
				2950	28		
-- --	--	29	5500			--	-- --
			2950		30		
AH4	2P60	31		5500		2P60	HP4 (HACR)
				2950	32		
-- --	--	33	5500			--	-- --
			2950		34		
AH5	2P60	35		5500		2P60	HP5 (HACR)
				2950	36		
-- --	--	37	5500			--	-- --
			2950		38		
AH6	2P60	39		5500		2P60	HP6 (HACR)
				2950	40		
-- --	--	41	5500			--	-- --
			2950		42		
			57,400	56100			

NOTES:
CONNECTED LOAD = 115.5 kVA
ESTIMATED DEMAND LOAD = 80.0kVA

LIGHTING PLAN NOTES

§1. 2 LAMPS ON ALL THE TIME.
§2. ROUTE THROUGH PE CELL MOUNTED ON ROOF FACING NORTH.
§3. SMOKE DETECTOR CONNECTED TO EMG. CKT. L1-5.



E201 LIGHTING PLAN
SCALE: 1/4" = 1'-0"

COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

LIGHTING PLAN

SHEET No.: E2	
DATE: 14 DECEMBER 1999	
REVISED:	REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

BEST COPY AVAILABLE

COMMUNITY SHELTER
HURRICANE FLOYD HOUSING INITIATIVE
NORTH CAROLINA

PLUMBING SPECIFICATIONS

GENERAL PROVISIONS

1. SCOPE: PROVIDE ALL LABOR, MATERIAL, AND EQUIPMENT IN ACCORDANCE WITH THESE SPECIFICATIONS AND THE ACCOMPANYING DRAWINGS TO PROVIDE A COMPLETE AND PROPERLY OPERATING PLUMBING SYSTEM FOR THE BUILDING.

   OBTAIN WATER & SEWER, GAS TAPS, AND ANY OTHER REQUIRED UTILITIES AND EXTEND SERVICE FROM SAME TO BUILDING AS SHOWN ON DRAWINGS. VISIT THE SITE FOR UNDERSTANDING OF THE WORK TO BE DONE BEFORE SUBMITTING BID.

   COORDINATE THIS WORK WITH THE WORK OF THE OTHER TRADES ON THE PROJECT. ALL PLUMBING IS TO BE ROUGHED IN WHILE THE BUILDING IS BEING CONSTRUCTED AT SUCH TIMES AS NOT TO DELAY THE GENERAL CONTRACTOR ON THE BUILDING.

2. GENERAL REQUIREMENTS: COMPLY WITH ALL FEDERAL, STATE, AND LOCAL REQUIREMENTS, CODES, RULES, AND ORDINANCES GOVERNING WORK ON THIS CHARACTER. PAY FOR AND OBTAIN NECESSARY CONSTRUCTION PERMITS AND CERTIFICATES OF INSPECTION.

   A. DRAWINGS: THE LOCATION OF THE PIPING RUNS ARE APPROXIMATE AND THE CONTRACTOR MUST MAKE ANY NECESSARY CHANGES IN THE PIPING RUNS, ETC., AND AT NO ADDITIONAL COST TO THE OWNER. OUTLET LOCATIONS ARE CRITICAL AND MUST BE LOCATED EXACTLY ACCORDING TO THE PLUMBING PLAN. COORDINATE THIS WORK WITH THE INSTALLERS OF EQUIPMENT FURNISHED AND INSTALLED BY OTHERS. REFER TO THE OTHER DRAWINGS FOR DETAILS OF THE BUILDING CONSTRUCTION AND THE OTHER MECHANICAL, ELECTRICAL, AND EQUIPMENT FEATURES.

   B. COORDINATION AND WORKMANSHIP: SCHEDULE THIS WORK SO THAT IT WILL BE PROPERLY COORDINATED WITH ALL OTHER TRADES. WORKMANSHIP SHALL BE IN ACCORDANCE WITH THE BEST PRACTICE FOR THE CLASS OF WORK INVOLVED. WORKMANSHIP SHALL ALLOW THE APPLIANCE TO OPERATE AS INTENDED AND BE INSTALLED TO BEST PROTECT THE PUBLIC AND OPERATORS FROM INJURY OR DAMAGE, AND TO PRESENT A NEAT, PLEASING, AND ORDERLY APPEARANCE.

MATERIALS AND PERFORMANCE

1. MATERIALS: ALL MATERIALS SHALL BE NEW AND OF THE QUALITY INDICATED BY THE SPECIFIED BRAND NAMES. SUBSTITUTIONS OF MATERIAL OF EQUAL QUALITY BY OTHER FIRST-LINE MANUFACTURERS MAY BE ACCEPTABLE PROVIDED A LIST OF SUCH SUBSTITUTIONS IS APPROVED IN WRITING BY FEMA REPRESENTATIVE
   A SUBSTITUTIONS LIST SHALL BE SUBMITTED IN TRIPLICATE WITHIN FIVE (5) DAYS AFTER THE CONTRACT IS LET.

2. BACKFILLING: PERFORM ALL NECESSARY EXCAVATING AND BACKFILLING REQUIRED FOR THIS INSTALLATION. PREPARE A PROPER BED OF SAND OR GRAVEL OR EQUIVALENT IN ROCK SCREENINGS SO AS TO ELIMINATE SHIMMING AND VOID SPACE UNDER ANY OF THE UTILITY SERVICE PIPES. BENDING OF ANY HARD PIPE WILL NOT BE PERMITTED. WHERE A CHANGE IN DIRECTION IS NECESSARY ON PRESSURE PIPES, "COMPATIBLE" COUPLINGS OR EQUAL SHALL BE USED AND BENDS MAY NOT EXCEED 90 DEGREES. ALL EXCAVATION BELOW THE BOTTOM OF FOOTINGS SHALL BE BACKFILLED WITH 2000 PSI CONCRETE. OTHER BACKFILL SHALL CONSIST OF 2-3" OF SAND OR ROCK SCREENINGS AND EARTH TO A FINAL LEVEL EQUAL TO ITS ORIGINAL CONDITION. IN THE EVENT THE BACKFILL SHOULD SETTLE BEFORE THE FINAL TOP SURFACE IS APPLIED, APPLY THE BACKFILL SHOULD SETTLE BEFORE THE FINAL TOP SURFACE IS APPLIED, APPLY ADDITIONAL BACKFILL TO SUSTAIN THE ORIGINAL LEVEL. CARE SHOULD BE TAKEN TO ADDITIONAL BACKFILL TO SUSTAIN THE ORIGINAL LEVEL. CARE SHOULD BE TAKEN TO MINIMIZE THE DUST LEVEL WHEN EXCAVATING AND BACKFILLING SO AS TO COMPLY WITH FEDERAL AND STATE E.P.A. REGULATIONS RELATING TO THIS TYPE OF WORK (FUGITIVE DUST).

3. PIPING INSTALLATION: CLEANOUTS MUST BE INSTALLED ON MINIMUM DROP LINES EVEN THOUGH NOT SHOWN ON THE BLUEPRINTS. USE REDUCING FITTINGS IN MAKING REDUCTIONS IN SIZE OF PIPE. REAM ALL PIPE AFTER CUTTING, THEN TURN PIPES ON END AND KNOCK OUT ALL LOOSE DIRT AND SCALE BEFORE INSTALLING. MAKE CHANGES IN HORIZONTAL DIRECTION OF SOIL AND WASTE PIPES WITH LONG RADIUS FITTINGS OR WITH "Y" BRANCHES AND 1/8" OR 1/16" BENDS. CONNECT SOIL STACKS AT BASE TO HORIZONTAL RUNS WITH "Y" CONNECTIONS.

   WATER SUPPLY PIPES TO FIXTURES AND WASTE PIPES FROM FIXTURES SHALL BE CENTERED IN THE PROPER PLACE RELATIVE TO THE CENTER LINE OF THE FIXTURE. NO OFFSETS WILL BE ALLOWED. ALL PIPES SHALL BE RUN MECHANICALLY STRAIGHT AND SQUARE WITH BUILDING LINES, EXCEPT FOR REQUIRED PITCH ON HORIZONTAL LINES, AND ALL CHANGES IN DIRECTION SHALL BE MADE WITH FITTINGS. WATER PIPING TO BE ROUTED IN WALLS, UNDER THE FLOOR SLAB, AND ON CEILINGS AS NOTED. WHERE WATER LINES ARE ROUTED UNDER THE FLOOR SLAB, NO MECHANICAL JOINTS SHALL BE MADE UNDER THE SLAB EXCEPT AS LISTED BELOW. WATER PIPING SHALL BE INSTALLED NOT TO EXERT VERTICAL NOR HORIZONTAL STRESSES ON THE SEATING OF UNIONS, UNIONS SHALL BE COPPER TYPE NIBCO #733 OR EQUAL.

   NO WAX, PUTTY, OR VARNISH WILL BE PERMITTED. CRACKED FITTINGS SHALL BE REMOVED AND REPLACED WITH NEW FITTINGS. MAKE THREADED JOINTS IN BRASS PIPE AND FITTING WITH PIPE THREADING TO THE SHOULDER OF THE FITTINGS. NO SLIP JOINTS OR COUPLING JOINTS IN BRASS PIPE WILL BE PERMITTED, EXCEPT ON THE FIXTURE SIDE OF THE TRAP.

4. WATER PIPE:

   JOINTS SHALL BE CLEANED AND DEBURRED AS RECOMMENDED BY THE MANUFACTURER AND FEDERAL, STATE AND LOCAL CODES AND SOLDERED AS LISTED BELOW. FLUX SHALL BE NON-CORROSIVE.

   ABOVE GRADE - WHERE FITTINGS ARE SOLDERED BOTH FITTINGS AND TUBING SHALL BE CLEANED AS DESCRIBED ABOVE. UNDER NO CIRCUMSTANCES SHALL DISSIMILAR METALS COME INTO DIRECT CONTACT WITH COPPER TUBING, E.G., GALVANIZED STRAPPING, HANGERS, OR CLAMPS TO SECURE THE TUBING.

   BELOW GRADE, OR FLOOR SLAB ON EARTH OR STONE FILL - HIGH TEMPERATURE, SOLDER, 1200 DEG. F OR GREATER MELTING POINT.
   NOTE: WATER PIPE TO BE PROPERLY SECURED AND ALIGNED SO AS NOT TO EXERT VERTICAL OR HORIZONTAL STRESSES ON THE SEATING OF THE MATING (MALE AND FEMALE) SURFACES OF THE UNIONS.

   A. MATERIALS - UNDERGROUND: TYPE "K" COPPER TUBE, SOFT TEMPER

   B. MATERIALS - ABOVEGROUND: TYPE "L" COPPER TUBE, HARD DRAWN, OR CPVC

   C. INSULATION: INSULATION FOR HOT AND COLD WATER PIPING SHALL BE 1/2" THICK ARMAFLEX UL LABELED OR FIBERGLASS 25 WITH ASJ/SSL FOIL/VINYL JACKET OR EQUAL. INSULATE ALL PIPING AND FITTINGS.

5. WASTE PIPING: INSTALL HORIZONTAL DRAIN AND WASTE PIPES WITH 1/4" FT. SLOPE.

   MATERIALS: PVC SCH. 40 OR CAST IRON - HUB TYPE WITH NEOPRENE JOINTS.

6. PIPE SLEEVES/ESCUTCHEONS: PROVIDE CHROME-PLATED ESCUTCHEONS ON ALL PIPES PASSING THROUGH WALLS, FLOORS, OR CEILINGS OF FINISHED ROOMS. ESCUTCHEONS TO BE BEATON & CADWELL, #10, 40, 6A OR EQUIVALENT WITH SET-SCREWS. PROVIDE ESCUTCHEONS ON ALL WASTE LINES FROM PLUMBING FIXTURES, WHETHER THROUGH WALLS, FLOORS, AND WHETHER CONCEALED BEHIND COUNTERS OR EXPOSED. PIPE SLEEVES SHALL BE PROVIDED WHEN PIPES PENETRATE FOUNDATION AND SHALL BE 1" LARGER THAN PIPE, SEAL SLEEVE WITH CAULKING.

7. PLUMBING FIXTURES: FURNISH AND INSTALL PLUMBING FIXTURES AS SHOWN ON DRAWINGS WITH ALL ACCESSORIES AND TRIM AS LISTED. ALL FIXTURES SHALL BE PROTECTED THROUGH THE COURSE OF THE CONSTRUCTION. ANY FIXTURE DAMAGED SHALL BE REPLACED WITHOUT ADDITIONAL EXPENSE TO THE OWNER.

8. CONNECTION TO OTHER FIXTURES: CONNECT BUILDING SERVICE PIPING, INCLUDING BUT NOT LIMITED TO WATER & DRAIN.

9. TESTS:

   A. DRAINAGE AND VENT PIPING - DRAINAGE AND VENT PIPING SHALL BE TESTED BEFORE THE PLUMBING FIXTURES ARE INSTALLED BY CAPPING THE OPENINGS AND FILLING THE ENTIRE SYSTEM WITH WATER AND ALLOWING IT TO STAND THUS FILLED NOT LESS THAN ONE (1) HOUR. INSPECT WATER LEVEL TO DETERMINE IF PIPING IS TIGHT.

   B. WATER PIPING - THE WATER SUPPLY PIPING LINES SHALL BE TESTED BEFORE THE PLUMBING FIXTURES ARE CONNECTED BY FILLING THE ENTIRE SYSTEM WITH POTABLE WATER AND APPLYING HYDROSTATIC PRESSURE OF 100 PSI AND ALLOWING TO STAND FOR NOT LESS THAN FOUR (4) HOURS AT THIS PRESSURE TO PROVE PLUMBING INTEGRITY.

10. DISINFECTION OF POTABLE WATER SYSTEM: UPON COMPLETION OF INSTALLATION DISINFECT THE WATER SYSTEM BY FILLING IT WITH SOLUTION CONTAINING 50 PARTS PER MILLION OF CHLORINE AND ALLOW IT TO STAND FOR NOT LESS THAN SIX (6) HOURS BEFORE FLUSHING THOROUGHLY AND RETURNING TO SERVICE. FURNISH CLEAN WATER SAMPLES TO THE LOCAL AUTHORITY FOR TESTING AFTER THE LINES HAVE BEEN DISINFECTED. THIS PROCEDURE TO BE IN ACCORDANCE WITH STATE PLUMBING CODE.

11. CLEANUP: CLEAN ALL PLUMBING FIXTURES AND EQUIPMENT THOROUGHLY BEFORE FINAL INSPECTION, LEAVING ALL READY FOR USE.

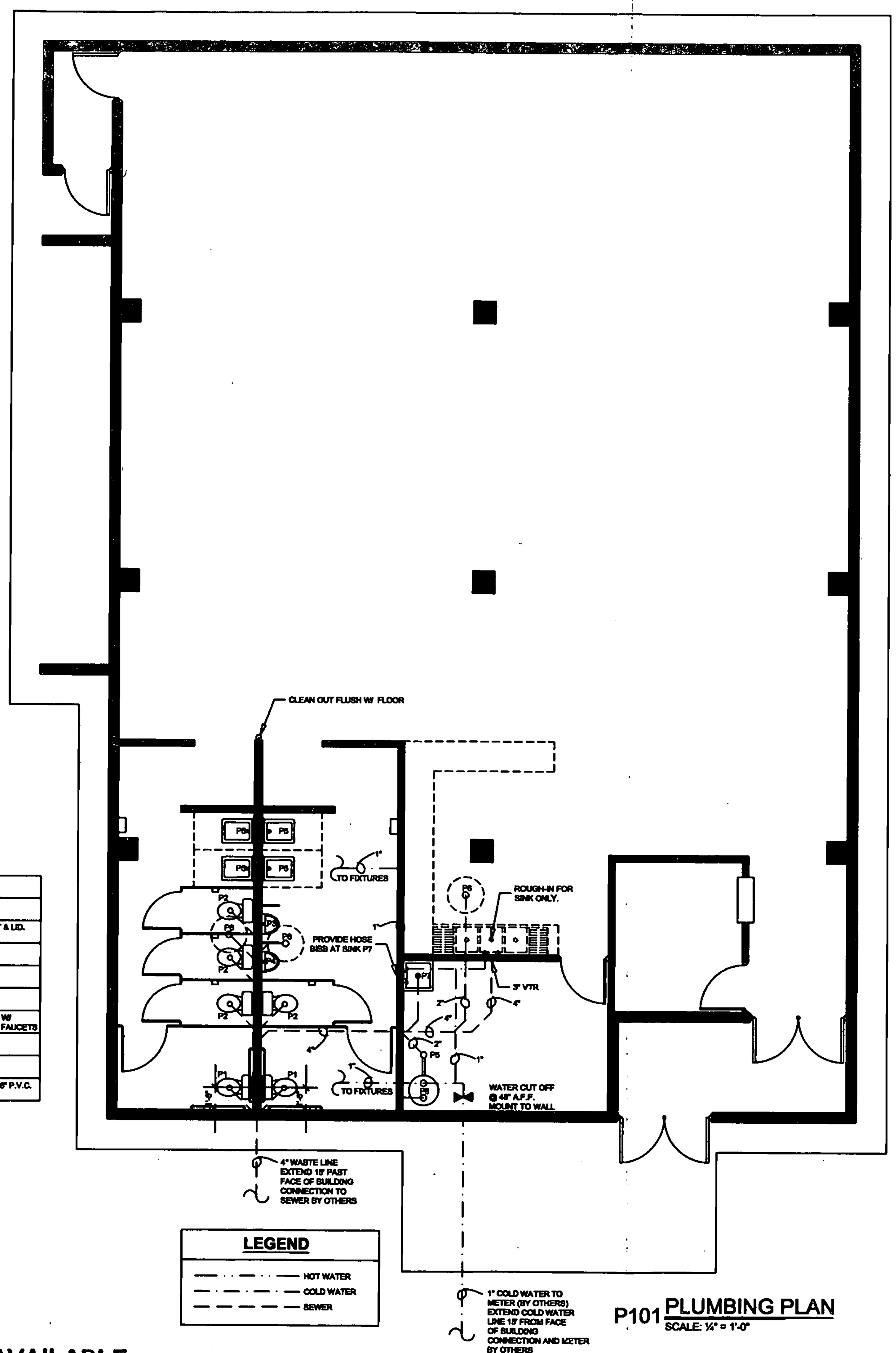
12. EXTENDED WARRANTY: WARRANT IN WRITING ANY EQUIPMENT OR MATERIALS USED IN THE INSTALLATION HAVING AN EXTENDED WARRANTY AS OFFERED BY THE MANUFACTURER. PROVIDE NEW OR REBUILT ASSEMBLIES TO THE SITE FOR ANY SUCH EQUIPMENT OR MATERIALS WHICH FAIL DURING THIS PERIOD, AND INSTALL AT NO ADDITIONAL COST TO THE OWNER.

PLUMBING SCHEDULE

ITEM	DESCRIPTION	MANUFACTURER	MODEL	REMARKS
P1	H.C. WATER CLOSET	MANSFIELD	137-160	WHITE C965 12" R.I. 18" HIGH H.C. W/ WHITE SEAT & LID. USE STANDARD COMPONENTS
P2	WATER CLOSET	MANSFIELD	135-160	WHITE C936 12" R.I. W/ WHITE SEAT & LID. USE STANDARD COMPONENTS
P3	URINAL	MANSFIELD	410	ADA URINAL - SIPHON - JET WHITE URINAL W/ FLUSH VALVE C199
P4	URINAL	MANSFIELD	475 SUBURBAN	WHITE URINAL W/ FLUSH VALVE C199
P5	LAVATORIES	ELJER	051-2964	20 1/2"x27" VITREOUS CHINA 4" CENTERS - WHITE W/ Z1231-79 LAVATORY CARRIER W/ DELTA 27T3834 FAUCETS
P6	FLOOR DRAIN	WADE	W1102-STD6	
P7	JANITOR SINK	ELJER	24"x24"x10"	MOLDED STONE NO. 231 DRIFT WHITE W/ DELTA 259 8" WALL MOUNTED SINK FAUCET
P8	HOT WATER TANK	A. O. SMITH	DLE/DRE-52	50 GAL. SINGLE PHASE 1 1/4" INLET/OUTLET W/ 26" P.V.C. OVERFLOW PAN PIPED TO FLOOR DRAIN

PLUMBING FIXTURE RUN OUT SCHEDULE

NO.	DESCRIPTION	WATER		WASTE	VENT
		COLD	HOT		
P1	H.C. WATER CLOSET	1/2"		3"	4"
P2	WATER CLOSET	1/2"		3"	4"
P3	URINAL	1/2"		3"	4"
P4	URINAL	1/2"		3"	4"
P5	LAVATORIES	1/2"	1/2"	1 1/2"	1 1/2"
P6	FLOOR DRAIN			1 1/2"	
P7	JANITOR SINK	1/2"	1/2"	3"	4"
	SINK ROUGH-IN	1/2"	1/2"	1 1/2"	1 1/2"



P101 PLUMBING PLAN
SCALE: 1/4" = 1'-0"

BEST COPY AVAILABLE

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.
Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.
Any substitution of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever. Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

PLUMBING PLAN

SHEET No.: P1	
DATE: 14 DECEMBER 1999	
REVISED:	REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

Appendix D
Case Study II – School Shelter Design (Kansas)

Overview

On May 3, 1999, an outbreak of tornadoes tore through parts of Oklahoma and Kansas leveling entire neighborhoods and killing 49 people; 6 in Kansas. Chisholm Life Skills Center in Wichita, Kansas sustained heavy damage from these storm systems. A double portable classroom was demolished and the roof system for the southwest classroom section of the school was destroyed. A mechanical room chimney collapsed onto an adjacent roof causing roof and wall failure. The roof membrane was damaged at several locations over the entire building.

PBA, an A/E firm in Wichita, was commissioned by the Unified School District No. 259 to assess damages and provide retrofit options including proposed locations for safe areas at Chisholm Center. Advantages and disadvantages for each proposal were listed, along with a recommendation and a cost estimate.

PBA recommended a centrally located classroom addition to replace the portable classrooms. The new addition would replace the lost facilities and also function as a tornado shelter. It would provide 840 square feet of usable floor space and be constructed with pre-cast concrete wall panels, a pre-cast double tee concrete roof structure, and roof mounted mechanical equipment. The design would meet the requirements of the newest local building codes for normal building use and technical guidelines in FEMA documents for tornado shelter use, including a design wind speed of 250 mph.

A major advantage of the design plan is that it could be implemented without disrupting school activity. Design plans for the new addition at the Chisholm Life Skills Center are provided in this appendix. The plans are preceded by the wind load analysis on which the design is based.

ASCE 7-98 Wind Load Analysis for Chisholm Life Skills Center Shop Addition

Using Exposure C

General Data

$K_z = 0.85$	Velocity Pressure Exposure Coefficient (Table 6-5 of ASCE 7-98)
$I = 1.00$	Importance Factor (see Chapter 5 of this manual)
$V = 250$	Wind Speed (mph) from FEMA Wind Zone Map (Figure 2-2 in this manual)
$K_{zt} = 1$	Topographic Factor (Figure 6-2 of ASCE 7-98)
$K_d = 1.00$	Wind Directionality Factor (Table 6-6 of ASCE 7-98)

$h = 14$	Building Height (ft)
$L = 56$	Building Length (ft)
$B = 35$	Building Width (ft)

Velocity Pressure (Section 6.5.10 of ASCE 7-98)

$q_z = (0.00256)(K_z)(K_{zt})(K_d)(V^2 I)$ $q_z = 136.00$ psf

$q_h = qz$

$q_h = 136.00$ psf

External Pressure Coefficients for Walls (Figure 6-3 in ASCE 7-98)

$L/B = 1.60$	$C_{p1} = 0.8$	windward wall	$B/L = 0.63$	$C_{p1} = 0.8$	windward wall
	$C_{p2a} = -0.38$	leeward wall		$C_{p2b} = -0.5$	leeward wall
	$C_{p3} = -0.7$	side wall		$C_{p3} = -0.7$	side wall

Roof Pressure Coefficients (Figure 6-3 in ASCE 7-98)

$h/L = 0.25$	$C_{p4a} = -0.9$	from 0–7 ft from windward edge
	$C_{p4b} = -0.9$	from 7–14 ft from windward edge
	$C_{p5} = -0.5$	from 14–28 ft from windward edge
	$C_{p6} = -0.3$	more than 28 ft from windward edge

(**Note:** Let $C_{p4} = C_{p4a} = C_{p4b}$ due to roof geometry)

Gust Factor

$G = 0.85$

Internal Pressure Coefficients for Buildings (Table 6-7 in ASCE 7-98)

$GC_{pipos} = 0.55$ for partially enclosed buildings

$GC_{pineg} = -0.55$for partially enclosed buildings

Design Wind Pressure for Rigid Buildings of All Heights (Section 6.5.12.2.1 of ASCE 7-98)

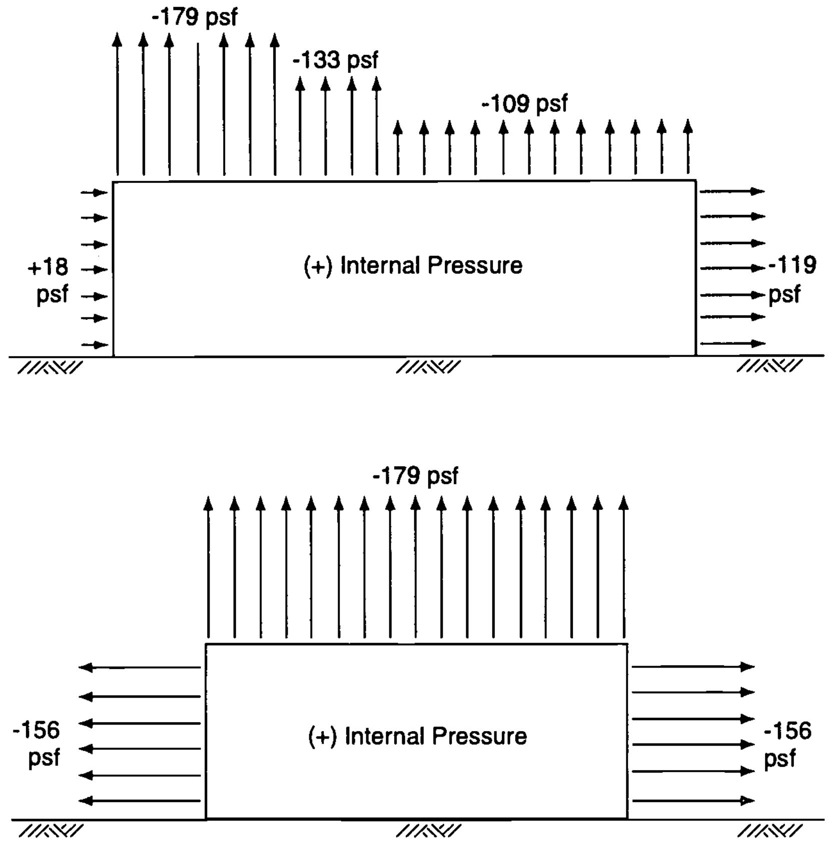
(for positive internal pressures)

$p_{wi} = (q_z)(G)(C_{p1} - q_h)(GC_{pipos})$	$p_{wi} = 17.68$	windward wall
$p_{lee2a} = (q_z)(G)(C_{p2a} - q_h)(GC_{pipos})$	$p_{lee2a} = -118.73$	leeward wall (wind parallel to ridge)
$p_{lee2b} = (q_z)(G)(C_{p2b} - q_h)(GC_{pipos})$	$p_{lee2b} = -132.60$	leeward wall (perpendicular to ridge)
$p_{side} = (q_z)(G)(C_{p3} - q_h)(GC_{pipos})$	$p_{side} = -155.72$	side wall
$p_{roof1} = (q_z)(G)(C_{p4} - q_h)(GC_{pipos})$	$p_{roof1} = -178.84$	roof pressures (0–14 ft from windward edge)
$p_{roof2} = (q_z)(G)(C_{p5} - q_h)(GC_{pipos})$	$p_{roof2} = -132.60$	roof pressures (14–28 ft from windward edge)
$p_{roof3} = (q_z)(G)(C_{p6} - q_h)(GC_{pipos})$	$p_{roof3} = -109.48$	roof pressures (more than 28 ft from windward edge)

(for negative internal pressures)

$p_{wi} = (q_z)(G)(C_{p1} - q_h)(GC_{pineg})$	$p_{wi} = 167.28$	windward wall
$p_{lee2a} = (q_z)(G)(C_{p2a} - q_h)(GC_{pineg})$	$p_{lee2a} = 30.87$	leeward wall (wind parallel to ridge)
$p_{lee2b} = (q_z)(G)(C_{p2b} - q_h)(GC_{pineg})$	$p_{lee2b} = 17.00$	leeward wall (perpendicular to ridge)
$p_{side} = (q_z)(G)(C_{p3} - q_h)(GC_{pineg})$	$p_{side} = -6.12$	side wall
$p_{roof1} = (q_z)(G)(C_{p4} - q_h)(GC_{pineg})$	$p_{roof1} = -29.24$	roof pressures (0–14 ft from windward edge)
$p_{roof2} = (q_z)(G)(C_{p5} - q_h)(GC_{pineg})$	$p_{roof2} = 17.00$	roof pressures (14–28 ft from windward edge)
$p_{roof3} = (q_z)(G)(C_{p6} - q_h)(GC_{pineg})$	$p_{roof3} = 40.12$	roof pressures (more than 28 ft from

Figure D-1
Design wind pressures when wind is parallel to ridge with positive internal pressures (Chisholm Life Skills Center Shop Addition)



Notes:
1. Positive pressure values act against the building surface.
2. Negative pressure values act away from the building surface.
3. Wind direction is from left to right on the top figure and going into the page on the lower figure.

BUDGETARY COST ESTIMATE FOR THE WICHITA, KANSAS, SHELTER

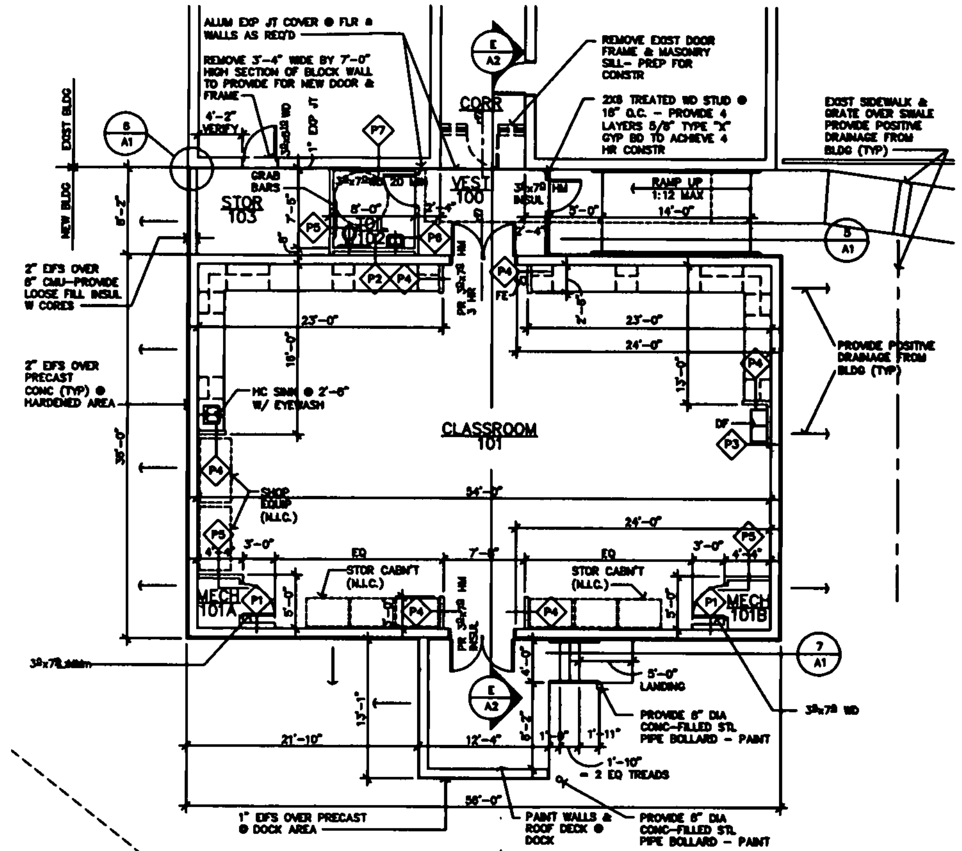
ESTIMATED CONSTRUCTION COSTS (+/- 20%)
(SHELTER AREA = 2,133 Square Feet)

CONSTRUCTION ITEM	COST
• Site work and general requirements	$ 16,200
• Utilities	$2,100
• Cast-in-place concrete	$22,900
• Pre-cast concrete structure	$ 57,700
• Metals	$ 8,700
• Woods and plastics	$ 21,000
• Thermal and moisture protection	$ 16,000
• Doors and hardware	$ 6,000
• Finishes	$ 6,000
• Specialties	$ 6,000
• Special equipment/technology	$6,000
• Electrical	$22,600
• Mechanical	$ 44,100
TOTAL CONSTRUCTION COSTS	$249,100
Profit and Fees	$ 24,900
TOTAL ESTIMATED CONSTRUCTION COSTS	**$274,000**
UNIT COST (PER SQUARE FOOT [SF])	**$128.00/SF**

NOTE: Currently, in this area of Kansas, school projects consisting of exterior loadbearing walls of CMU with brick veneer, interior non-loadbearing CMU walls, and open-web steel joist roof systems with metal decks are budgeted at $95.00–$100.00/ft^2.

WITCHITA SCHOOL TORNADO SHELTER

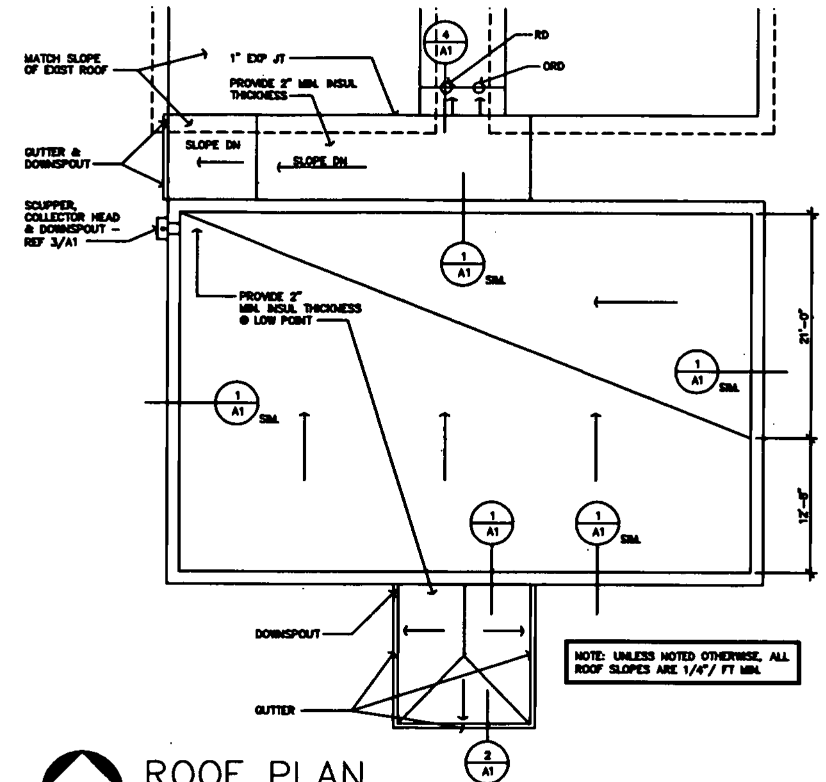
WICHITA, KANSAS



FLOOR PLAN

0' 4' 8' 16'

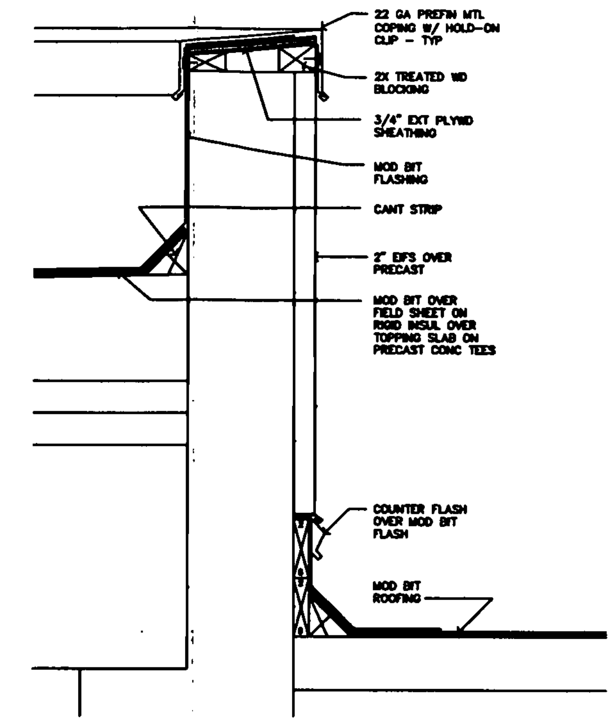
1/8"=1'-0"



ROOF PLAN

0' 4' 8' 16'

1/8"=1'-0"



1 PARAPET DETAIL

1 1/2"=1'-0"

GENERAL NOTES:

1. FINISHES-
   - -VEST 100 - MATCH EXIST, SAT CLG
   - -SHOP/SHELTER 101 - NO FINISHES, SEAL CONC FLR, PAINT GYP BD, BASE W GYP BD
   - -TOIL 102 - SEALED CONCRETE FLOOR, 48"H FRP ON WALLS
   - -STOR 103 - NO FINISHES
2. PROVIDE SPACE IN NEW CABINET FOR THE FOLLOWING PER FEMA REGULATIONS:
   1. FLASH LIGHTS
   2. FIRST-AID KIT
   3. NOAA WEATHER RADIO
3. ALL COLOR SELECTIONS BY OWNER
4. TORNADO SAFER AREA SHALL BE CONSTRUCTED PER THE NATIONAL PERFORMANCE CRITERIA FOR TORNADO SHELTERS DATED 5/28/99

SPECIFICATION NOTES:

1.	ROOF MEMBRANE:	TAMKO 102FR AWAPLAN PREMIUM FR
2.	ROOF INSULATION:	EPS 1.50 PCF DENSITY W/ 1/2" COVER BOARD HOT MOPPED TO ROOF DECK - MAX 4'X4' SHEETS
3.	EIFS:	DRYVIT SYSTEMS, 2" EPS INSUL, 1.0 PCF, PANZER 20 MESH, SAND FINISH, COLOR AS SELECTED BY OWNER
4.	METAL STUDS:	25 GAUGE
5.	HM DOORS:	STEELCRAFT MFG. CO. 14 GA FACES, 14 GA FRAMES - ANCHOR FRAMES W/ (4) 3/8" X 6" EXP ANCHORS PER JAMB
6.	WOOD DOORS:	WEYERHAEUSER 1 3/4" SOLID CORE W/ HARDWOOD VENEER FACES - STAIN, CLEAR FINISH IN 16 GA HM FRAME W/ STUD ANCHORS
7.	SUSP ACOUST CLG:	ARMSTRONG NATURAL FISSURED 2'X4'
8.	MILLWORK:	AWI CUSTOM GRADE - LAMINATE FACED, LAMINATE COUNTERTOPS & BACKSPLASHES, LAMINATE COLOR SELECTIONS BY OWNER

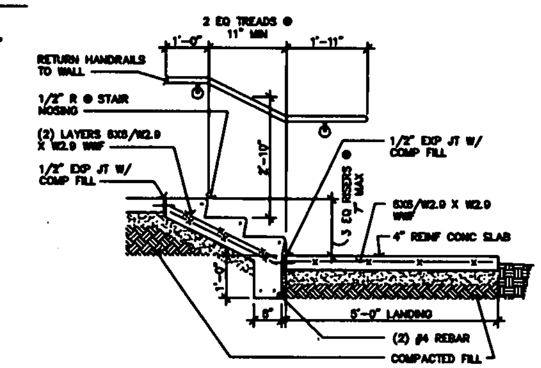
DOOR HARDWARE:

1. (2) PR HM DOOR @ CLASSRM ENTRY/EXIT
   - -1 1/2 PR HINGES
   - -REMOVABLE MULLION
   - -CLOSER
   - -PANIC DEVICE
   - -THRESHOLD
   - -WEATHERSTRIPPING
2. TOILET 102 WOOD DOOR
   - -1 1/2 PR HINGES
   - -CLOSER
   - -LEVER LOCKSET (PRIVACY FUNCTION)
   - -WALL MOUNTED DOOR STOP
3. VEST 100 HM ENTRY DOOR
   - -1 1/2 PR HINGES
   - -CLOSER
   - -PANIC DEVISE
   - -PULL HANDLE
   - -THRESHOLD - CLEAR ANOD
   - -WEATHERSTRIPPING

   NOTE: UNLESS NOTED OTHERWISE, FIN TO BE DARK BRONZE ANOD.
4. (2) WOOD DOORS @ MECH ROOMS
   - -1 1/2 PR HINGES
   - -LEVER LOCKSET (STOREROOM FUNCTION)
   - -DOOR STOP
   - -HOLD OPEN
5. STORAGE 103 WOOD DOOR
   - -1 1/2 PR HINGES
   - -LEVER LOCKSET (STOREROOM FUNCTION)
   - -DOOR STOP

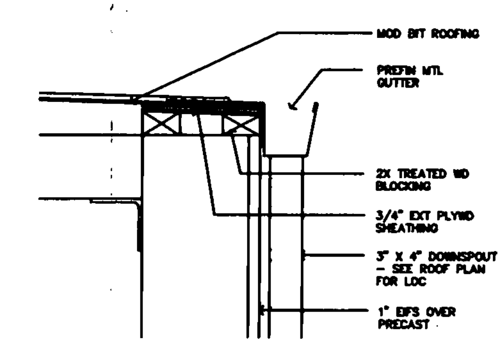
PARTITION SCHEDULE

P1	8" MTL STUD @ 16" O.C. W/ 5/8" GYP BD ON EXPOSED SIDE OF STUD - EXTEND TO 10'-0" AFF
P2	3 5/8" MTL STUD @ 16" O.C. W/ 5/8" GYP BD ON EXPOSED SIDE OF STUD - EXTEND TO 4" ABV FIN CLG
P3	3 5/8" MTL STUD @ 16" O.C. W/ 5/8" GYP BD ON EXPOSED SIDE OF STUD - EXTEND TO 10'-0" AFF
P4	3 5/8" MTL STUD @ 16" O.C. W/ 5/8" GYP BD EA SIDE OF STUD - EXTEND TO 10'-0" AFF
P5	3 5/8" MTL STUD @ 16" O.C. W/ 5/8" GYP BD EA SIDE OF STUD W/ SOUND BATTS - EXTEND TO STRUCT ABV
P6	3 5/8" MTL STUD @ 16" O.C. W/ 5/8" TYPE "X" GYP BD EA SIDE OF STUD W/ SOUND BATTS - EXTEND TO STRUCT ABV
P7	1 5/8" MTL STUD @ 16" O.C. W/ 5/8" TYPE GYP BD ON EXPOSED SIDE OF STUD - EXTEND TO 4" ABV FIN CLG



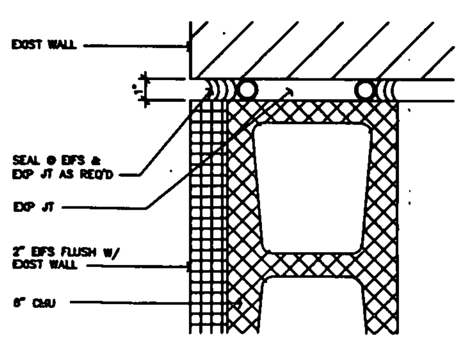
7 SECT @ DOCK STAIR

1/2"=1'-0"



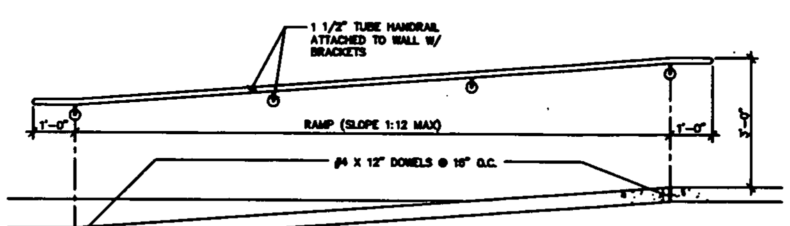
2 ROOF DETAIL @ DOCK

1 1/2"=1'-0"



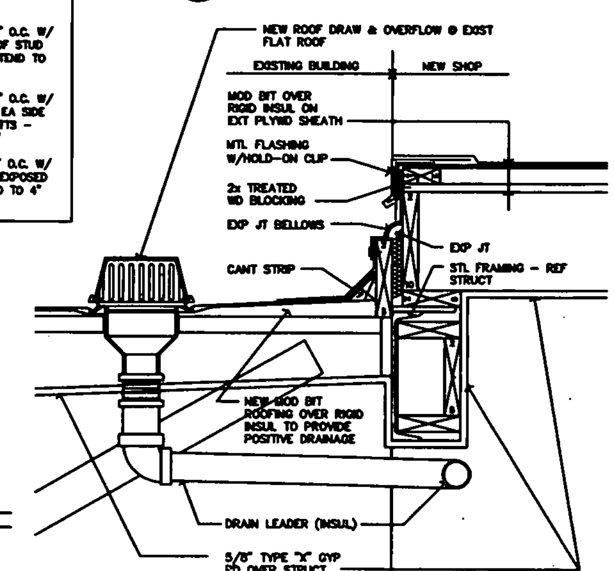
6 DETAIL @ EIFS JT

3"=1'-0"



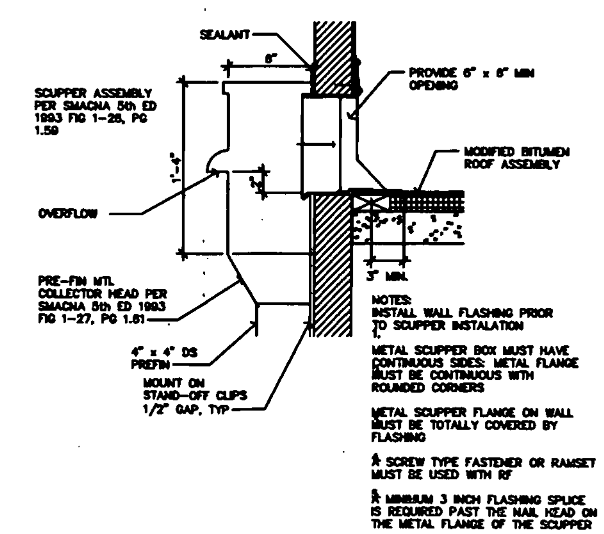
5 DETAIL @ RAMP

1/2"=1'-0"



4 ROOF DETAIL @ EXP JT

1 1/2"=1'-0"



3 SCUPPER DETAIL

1 1/2"=1'-0"

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.

Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.

Any substitutions of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever.

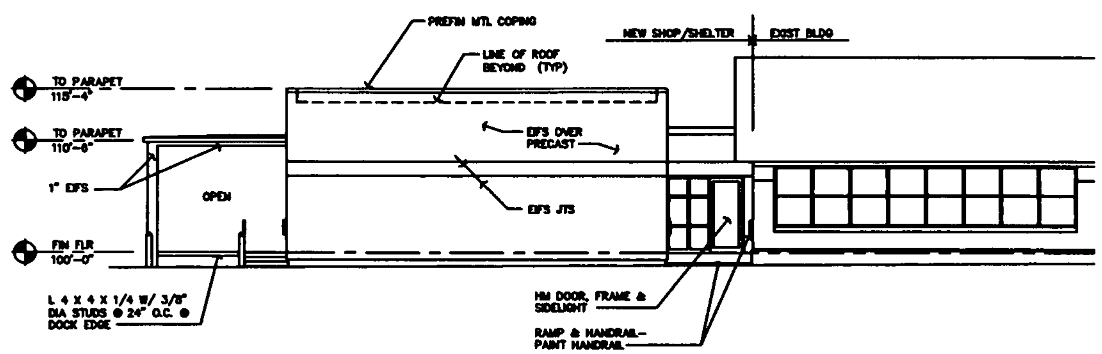
Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintainence thereof.

SITE & FLOOR PLAN

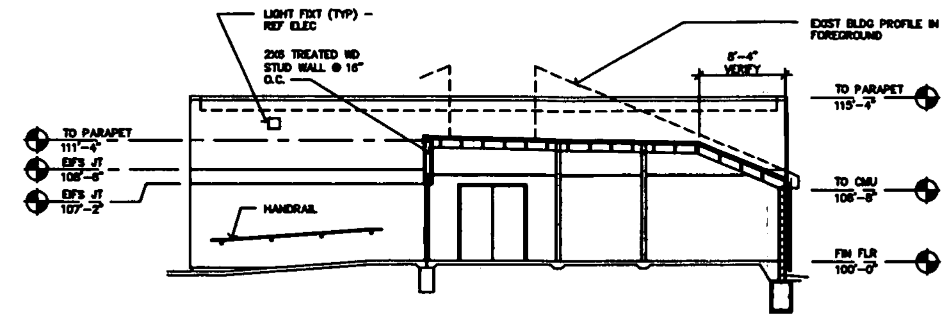
SHEET No.: A1	
DATE: 7 MARCH 2000	
REVISED:	REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

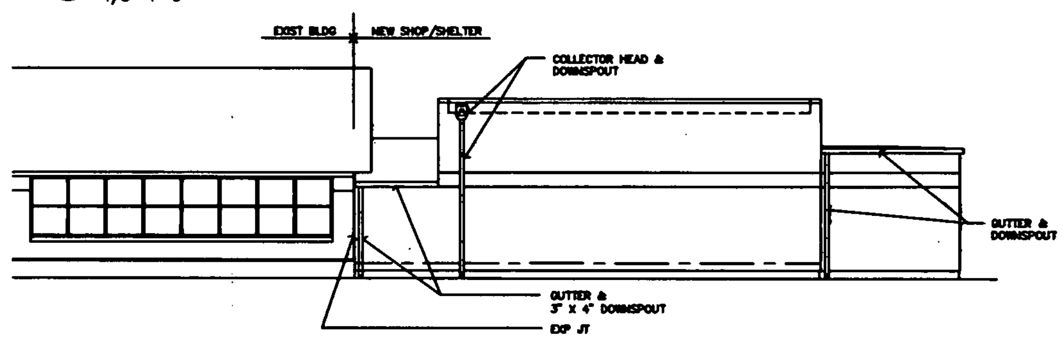
BEST COPY AVAILABLE



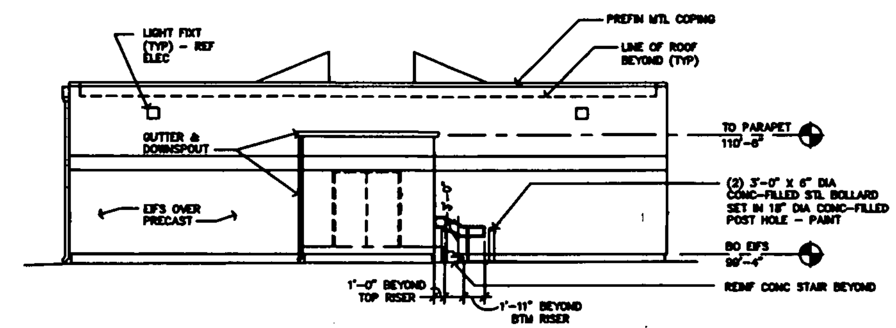
Ⓐ BUILDING SECTION – EAST
1/8"=1'-0"



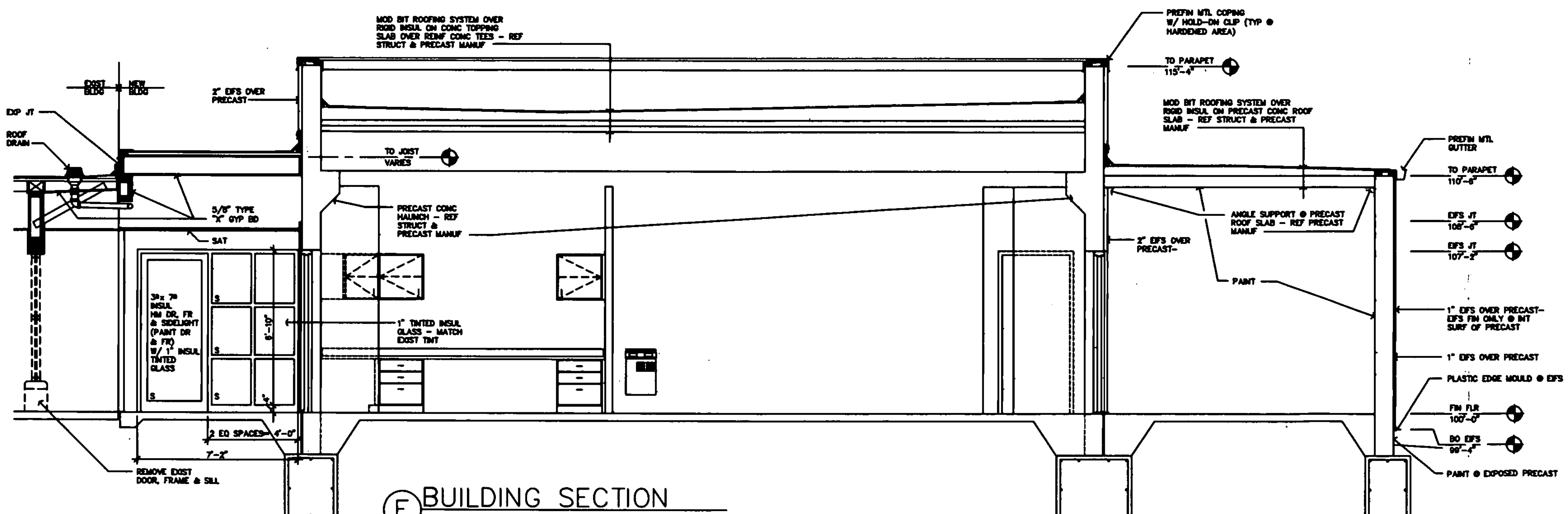
Ⓑ BUILDING SECTION – NORTH
1/8"=1'-0"



Ⓒ BUILDING SECTION – WEST
1/8"=1'-0"



Ⓓ BUILDING SECTION – SOUTH
1/8"=1'-0"



Ⓔ BUILDING SECTION
3/8"=1'-0"

WITCHITA SCHOOL TORNADO SHELTER
WICHITA, KANSAS

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.

Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.

Any substitutions of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrent the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever.

Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintainence thereof.

ELEVATIONS & SECTIONS

SHEET No.: A-2
DATE: 7 MARCH 2000
REVISED: | REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

BEST COPY AVAILABLE

WITCHITA SCHOOL TORNADO SHELTER

WICHITA, KANSAS

STRUCTURAL GENERAL NOTES

A. DESIGN CRITERIA

1. BUILDING CODE: UNIFORM BUILDING CODE (UBC), 1997 EDITION, INCLUDING LOCAL SUPPLEMENTS, ASCE 7-95, & FEMA TORNADO PERFORMANCE CRITERIA.

2. GRAVITY LOADS:

LOCATION	UNIFORM LIVE LOAD	CONCENTRATED LIVE LOAD	UNIFORM DEAD LOAD
ROOF	20 PSF	--------	18 PSF
GROUND SNOW	15 PSF	--------	------
SLAB ON GRADE	100 PSF	2000 LB	------

LIVE LOAD REDUCTION ON SUPPORTING ELEMENTS SHALL BE IN ACCORDANCE WITH THE UNIFORM BUILDING CODE (UBC), 1997 EDITION. NO LIVE LOAD REDUCTION OF ROOF LOADING IS PERMITTED. DRIFTING OF SNOW IN ACCORDANCE WITH CODE. UNIFORM DEAD LOAD IS ADDITIVE TO ACTUAL STRUCTURAL WEIGHTS.

3. LATERAL LOADS:

A. BASIC WIND SPEED SHALL BE 250 MPH, EXPOSURE C, I=1.0.

B. SEISMIC LOAD SHALL BE FOR ZONE 1.

Z=0.075 I=1.00 RW=8 Ca=0.19 Cv=0.26 SOIL PROFILE TYPE=SE

B. SOIL PREPARATION AND FOUNDATIONS

1. A COPY OF THE SUBSURFACE GEOTECHNICAL REPORT IS AVAILABLE FOR INSPECTION AT THE ARCHITECT'S PLACE OF BUSINESS.

2. SOIL SUPPORTED FOUNDATIONS:

A. DESIGN BEARING PRESSURE (NET) IS 2,500 PSF FOR FOUNDATIONS BEARING ON UNDISTURBED SOIL OR 1,500 PSF ON APPROVED ENGINEERED FILL MATERIAL. BEARING MATERIALS SHALL BE VERIFIED BY A LICENSED SOIL ENGINEER.

B. ALL FOUNDATIONS ARE DESIGNED WITH FORMED SIDES. IF EARTH FORMED SIDES ARE APPROVED BY THE ENGINEER, THE TOP 7 1/4" SHALL BE FORMED TO THE DESIGN DIMENSION AND ONE INCH SHALL BE ADDED TO EACH SIDE OF THE EARTH FORMED AREA TO PROVIDE ADEQUATE COVER OVER THE REINFORCING AT THE CONTRACTOR'S EXPENSE.

C. REINFORCING SHALL BE SUPPORTED FROM ABOVE OR WITH 3" SBP (WITH BOTTOM PLATE) AT 4'-0" CENTERS MAXIMUM FOR ALL FOUNDATION REINFORCING.

3. DO NOT BACKFILL FOUNDATION WALLS UNTIL THE RESTRAINING SLABS OR ADEQUATE BRACING ARE IN PLACE. ALL BACKFILL SHALL BE PLACED AND COMPACTED IN ACCORDANCE WITH THE SPECIFICATION.

4. EXTERIOR SLABS SHALL SLOPE AWAY FROM THE STRUCTURE A MINIMUM OF 1/4" PER FOOT UNLESS NOTED OTHERWISE.

C. CAST-IN-PLACE CONCRETE

1. ALL STRUCTURAL CONCRETE HAS BEEN DESIGNED IN ACCORDANCE WITH THE ACI 318-95 AND THE BUILDING CODE.

2. THE CONCRETE REQUIREMENTS ARE:

A. CEMENT SHALL BE TYPE I OR II CONFORMING TO ASTM C150.

B. FINE AND COURSE AGGREGATES SHALL CONFORM TO ASTM C33.

C. MIX REQUIREMENTS ARE:

LOCATION	MIN. F'C PSI	MIN. F'CI PSI	MIN. CEM. PCY	MAX. W/C RATIO	AIR ENT.
FOUNDATIONS	4000	N/A	470	0.50	5%+/-1%
GRADE BEAMS	4000	N/A	470	0.50	5%+/-1%
INTERIOR SLAB*	4000	N/A	564	0.50	NR

* SLAB ON GRADE SHALL HAVE A FLEXURAL STRENGTH OF 650 PSI.

D. CONCRETE CLEAR COVER OVER REINFORCING SHALL BE IN ACCORDANCE WITH ACI 318-95, AS LISTED BELOW, UNLESS NOTED OTHERWISE.

LOCATION	CLEAR COVER INCHES
CAST AGAINST EARTH	3
EXPOSED TO EARTH OR WEATHER #6 AND LARGER	2
EXPOSED TO EARTH OR WEATHER #5 AND SMALLER	1 1/2
SLABS AND WALLS NOT EXPOSED TO WEATHER	3/4
BEAMS AND COLUMNS NOT EXPOSED TO WEATHER	1 1/2
SLABS ON GRADE (COVER FROM TOP OF SLAB)	1 1/2

3. CONCRETE REINFORCING SHALL MEET THE FOLLOWING:

A. REINFORCING BARS SHALL CONFORM TO THE REQUIREMENTS OF ASTM A615 GRADE 60. REINFORCING BARS REQUIRED TO BE WELDED SHALL CONFORM TO THE REQUIREMENTS OF ASTM A706 GRADE 60. WELDING OF REINFORCING OTHER THAN SPECIFIED IS PROHIBITED.

B. WELDED WIRE FABRIC SHALL CONFORM TO THE REQUIREMENTS OF ASTM A185.

C. ALL REINFORCING SHALL BE CONTINUOUS. CONTINUOUS BARS SHALL LAP IN ACCORDANCE WITH TABLE A UNLESS NOTED OTHERWISE. PROVIDE BENT BARS AT ALL CORNERS.

D. WELDED WIRE FABRIC SHALL LAP ONE FULL SQUARE PLUS 2".

E. SHOP DRAWINGS SHALL BE SUBMITTED WITH REINFORCING STEEL DETAILED IN ACCORDANCE WITH ACI 315.

4. FORMING AND EMBEDMENTS SHALL MEET THE FOLLOWING:

A. ALL EXPOSED EDGES OF CONCRETE SHALL BE CHAMFERED 3/4" INSIDE FORMS OR TOOLED TO 3/4" RAD., UNLESS NOTED OTHERWISED.

B. SLABS ON GRADE SHALL HAVE CONSTRUCTION JOINTS AND CONTROL JOINTS (SAWN JOINTS), LOCATED AS SHOWN ON THE DRAWINGS. CONTRACTOR SHALL LOCATE SLAB JOINTS ON SHOP DRAWINGS.

C. WHERE NECESSARY, VERTICAL CONSTRUCTION JOINTS SHALL BE LOCATED AT MIDSPAN. ALL JOINTS SHALL BE THOROUGHLY CLEANED AND PURPOSELY ROUGHENED TO 1/4" PRIOR TO PLACING ADJACENT CONCRETE.

D. THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE DESIGN OF ALL FORMING, TEMPORARY BRACING AND SHORING.

E. NO ALUMINUM SHALL BE EMBEDDED IN CONCRETE. CONDUITS AND PIPING EMBEDDED IN CONCRETE SHALL BE SPACED A MINIMUM OF FOUR DIAMETERS AND THE OUTSIDE DIAMETER SHALL BE LESS THAN 30% OF THE MEMBER THICKNESS PLACED BETWEEN LAYERS OF REINFORCING.

D. PRECAST CONCRETE

1. ALL PRECAST CONCRETE PRODUCTS SHALL BE DESIGNED IN ACCORDANCE WITH THE BUILDING CODE, ACI 318-95 AND PCI DESIGN HANDBOOK FIFTH EDITION. SHOP DRAWINGS AND CALCULATIONS OF PRECAST PRODUCTS AND CONNECTIONS SHALL BE SUBMITTED BEARING THE SEAL OF AN ENGINEER REGISTERED IN THE STATE WHERE THE PROJECT IS LOCATED. PRECAST SUPPLIER SHALL BE CERTIFIED BY PCI.

2. ADDITIONAL DESIGN REQUIREMENTS ARE:

A. BEARING PADS SHALL BE DESIGNED AND SUPPLIED BY THE PRECAST MANUFACTURER TO ABSORB ALL REQUIRED MOVEMENT WITHOUT SLIPPAGE. THE MINIMUM THICKNESS OF BEARING PADS SHALL BE 1/4" UNLESS NOTED OTHERWISE. BEARING PADS SHALL BE LOCATED A MINIMUM OF 1/2" AWAY FROM THE FACE OF THE SUPPORT.

B. MEMBERS SHALL NOT BE REMOVED FROM THE FORMS UNTIL THE CONCRETE HAS REACHED SUFFICIENT STRENGTH TO RESIST REMOVAL WITHOUT DAMAGE. IN NO CASE, SHALL PRECAST MEMBERS BE REMOVED PRIOR TO ATTAINING A MINIMUM COMPRESSIVE STRENGTH OF 2,500 PSI.

C. PRECAST MEMBERS AND THEIR CONNECTIONS SHALL BE DESIGNED FOR THE LOADS SHOWN ON THE DRAWINGS, IN ADDITION TO THE SELF WEIGHT OF THE MEMBER AND FOR ALL THE CONDITIONS NOTED IN ACI 318-95. CONNECTIONS SHALL BE DESIGNED FOR FORCES AND MOVEMENTS DUE TO VOLUMETRIC CHANGES RESULTING FROM TEMPERATURE CHANGE, ELASTIC DEFORMATIONS, CREEP AND SHRINKAGE. BEAM TO BEAM AND BEAM TO COLUMN CONNECTIONS SHALL BE DESIGNED FOR A MINIMUM ULTIMATE FORCE (HORIZONTAL SHEAR OR TENSION) OF 6 KIPS.

D. ALL COLUMNS AND WALL PANELS, SUPPORTED ON FOUNDATIONS, SHALL HAVE THE HORIZONTAL JOINT GROUTED WITH A NON-SHRINK GROUT WHICH HAS A COMPRESSIVE STRENGTH AT 28 DAYS EQUAL TO OR GREATER THAN THAT OF THE SUPPORTED MEMBER.

E. FLOOR AND ROOF MEMBERS SHALL BE CONNECTED TO ADJACENT MEMBERS WITH WELDED SIDE ANCHORS SPACED AT 10'-0" CENTERS MAXIMUM, AND A MINIMUM OF TWO ANCHORS PER MEMBER ON EACH SIDE UNLESS NOTED OTHERWISE.

3. MATERIALS SHALL MEET THE FOLLOWING REQUIREMENTS:

CONCRETE	MIN. F'C PSI	MIN. CMT FAC	MAX. W/C RAT	AIR ENT.
EXT. WALL PANELS	5000	470	0.50	4%+/-1%
ROOF TEES*	5000	470	0.50	NR

REINFORCING	ASTM	GRADE
REINFORCING BARS	A615	60
WELDABLE REINFORCING BARS	A706	60
WELDED WIRE FABRIC	A185	60

E. MASONRY

1. ALL MASONRY HAS BEEN DESIGNED BASED ON ALL MASONRY RECEIVING SPECIAL FIELD INSPECTION.

2. CONCRETE MASONRY UNITS (CMU) MATERIALS SHALL BE:

A. ALL CONCRETE MASONRY UNITS (CMU) SHALL BE TWO CELL LIGHTWEIGHT AGGREGATE UNITS WITH A SPECIFIED MINIMUM COMPRESSIVE STRENGTH OF 2000 PSI ON NET AREA (1000 PSI ON GROSS AREA) AT 28 DAYS CONFORMING TO ASTM C90. CMU LOCATED BELOW GRADE, SHALL BE NORMAL WEIGHT AGGREGATE UNITS.

B. ALL MORTAR SHALL BE TYPE "S" OR "M" WITH A MINIMUM MORTAR COMPRESSIVE STRENGTH OF 1800 PSI AT 28 DAYS CONFORMING TO ASTM C270. THE MINIMUM COMPRESSIVE STRENGTH (f'M) OF A PRISM ASSEMBLED OF CMU AND MORTAR SHALL BE 1350 PSI AT 28 DAYS ON THE NET AREA.

C. GROUT SHALL CONFORM TO ASTM C476 WITH 3/8" AGGREGATE WITH THE FOLLOWING REQUIREMENTS:

	MIN. F'C PSI	MIN. CMT PCY	MAX. W/C RATIO	AIR ENT.
CMU GROUT	3000	611	0.65	NR

D. REINFORCING STEEL SHALL MEET THE REQUIREMENTS OF ASTM A615, GR 60.

E. JOINT REINFORCING STEEL SHALL MEET THE REQUIREMENTS OF ASTM A82 WIRE WITH A MINIMUM YIELD GREATER THAN 70 KSI. LONGITUDINAL WIRES SHALL BE 9 GA (0.1483" DIA) WITH TRUSS TYPE WIRES CONNECTED AT 16" CENTERS. REINFORCING SHALL BE MILL GALVANIZED PER ASTM A641, CLASS 3.

3. HORIZONTAL WALL REINFORCING

A. PROVIDE BOND BEAM COURSES IN ALL WALLS AT THE TOP OF WALL OR PARAPET, AT FLOOR LEVELS (ABOVE GRADE), AT TOP OF OPENINGS OR IMMEDIATELY ABOVE LINTELS, BELOW OPENINGS AND AT BEARING LOCATIONS. BOND BEAMS SHALL BE REINFORCED AS FOLLOWS:

WALL TYPE	BOND BEAM REINF.
8" CMU	2-#5

ALL INTERIOR STRUCTURAL WALLS (SHEAR AND/OR BEARING) SHALL HAVE INTERMEDIATE BOND BEAMS LOCATED AT THE SAME LEVELS AS EXTERIOR BOND BEAMS.

B. PROVIDE BOND BEAMS AT INTERMEDIATE LOCATIONS IN EVERY SIXTH COURSE (IE: 4'-0" CENTERS).

4. VERTICAL REINFORCING

A. PROVIDE VERTICAL REINFORCING (NORMAL REINFORCING) IN GROUT FILLED CELLS IN ALL WALLS AS FOLLOWS, UNLESS NOTED OTHERWISE:

WALL TYPE	REINF. IN FILLED CELLS	MAXIMUM SPACING OF FILLED CELLS
8" CMU	1-#5	32"

B. PROVIDE AN ADDITIONAL VERTICAL REINFORCING BAR WITH DOWELS INTO SUPPORTING MEMBERS, WITH SAME SIZE AND LENGTH AS THE NORMAL REINFORCING BAR, AT THE FOLLOWING LOCATIONS:

1. ON EACH SIDE OF A CONTROL OR ISOLATION JOINT
2. AT INTERSECTION OF WALLS
3. EACH SIDE OF A WALL OPENING
4. AT EACH END OF WALL
5. AT EACH BEAM BEARING

C. VERTICAL REINFORCING SHALL EXTEND CONTINUOUSLY FROM THE TOP OF THE SUPPORTING MEMBER TO EMBED AT LEAST 6" INTO THE TOP BOND BEAM. THERE SHALL BE A DOWEL, CAST INTEGRAL WITH THE SUPPORTING MEMBER, FOR EACH VERTICAL REINFORCING BAR EXCEPT AS NOTED.

5. REINFORCING SHALL MEET THE FOLLOWING LAP, SPLICE AND EMBEDMENT REQUIREMENTS:

REINF. BAR SIZE	LAP OR SPLICE LENGTH IN WALL	FOUNDATION EMBEDMENT WITH HOOK INTO FOUND.	DOWELS STRAIGHT EMBEDMENT INTO FOUND.
JOINT	18"	N/A	N/A
4	24"	8"	15"
5	25"	10"	19"

HOOKS IF USED SHALL BE ACI STANDARD HOOKS.

6. CELLS WHICH CONTAIN REINFORCING STEEL (VERTICAL CELLS, BOND BEAMS AND LINTELS) SHALL BE FILLED SOLIDLY WITH GROUT.

7. VERTICAL CELLS TO BE FILLED SHALL HAVE VERTICAL ALIGNMENT SUFFICIENT TO MAINTAIN A CLEAR UNOBSTRUCTED CONTINUOUS VERTICAL CELL.

8. BOND BEAM AND JOINT REINFORCING FOR INTERIOR AND EXTERIOR WALLS SHALL BE CONTINUOUS THROUGHOUT, EXCEPT AT CONTROL AND ISOLATION JOINTS, IT SHALL BE AS FOLLOWS:

A. INTERMEDIATE REINFORCING SHALL BE DISCONTINUOUS AT CONTROL JOINTS. REINFORCEMENT IN BOND BEAMS AT FLOOR AND ROOF DIAPHRAGM LEVELS SHALL BE CONTINUOUS.

B. AT ISOLATION JOINTS, ALL REINFORCING SHALL BE DISCONTINUOUS.

9. BARS AROUND PERIMETER OF OPENINGS SHALL EXTEND NOT LESS THAN 40 BAR DIAMETERS OR 24", WHICHEVER IS LARGER, BEYOND THE CORNER OF THE OPENING. VERTICAL JAMB BARS SHALL BE THE SAME SIZE AND NUMBER AS THE NORMAL VERTICAL REINFORCING. FOUNDATION DOWELS ARE ONLY

10. LINTELS OVER OPENINGS, UNLESS NOTED OTHERWISE, SHALL BE:

OPENING	LINTEL
< 4'-0"	8"X8" CMU BOND BEAM W/ 2-#5 & 8" BEARING
> 4'-0", < 8'-0"	8"X16" CMU BOND BEAM W/ 2-#5 T&B & 16" BEARING
> 8'-0"	SEE PLANS

11. ALL MASONRY IN CONTACT WITH SOIL SHALL BE NORMAL WEIGHT UNITS AND HAVE ALL VOIDS FILLED WITH GROUT.

F. STRUCTURAL WOOD

1. ALL WOOD STRUCTURES HAVE BEEN DESIGNED IN ACCORDANCE WITH THE BUILDING CODE.

2. THE DESIGN OF THE STRUCTURE IS BASED UPON THE USE OF THE FOLLOWING PRODUCTS:

A. WOOD

USE	WOOD TYPE	GRADE	Fb PSI	Fcp PSI	E PSI
JOISTS	SOUTHERN PINE	#2	1,050	1,450	1,600,000
STUDS (2 X 4)	DOUGLAS FIR	#1	1,000	1,450	1,700,000
(2 X 6)	DOUGLAS FIR	#2	875	1,300	1,600,000

ALL MEMBERS SHALL BE SURFACED DRY AND HAVE A MAXIMUM MOISTURE CONTENT OF 19 PERCENT. STRESS INCREASE SHALL BE 15% FOR LIVE LOAD ONLY.

B. ROOF SHEATHING SHALL BE 1/2", 7/16" OR 15/32" APA RATED PLYWOOD OR PARTICLE BOARD, 24/0 SPAN RATING, EXPOSURE 1, LAID IN A STAGGERED PATTERN, WITH EDGE CLIPS BETWEEN SUPPORTS, AND CONTINUOUS OVER A MINIMUM OF THREE SUPPORTS.

C. ALL WOOD PRODUCTS IN DIRECT CONTACT WITH THE FOUNDATION SHALL BE PRESSURE TREATED PER SPECIFICATION.

3. CONNECTIONS SHALL MEET THE FOLLOWING REQUIREMENTS:

A. ALL BOLTS SHALL BE ASTM A307. OVERSIZED WASHERS SHALL BE USED BETWEEN THE HEAD OR NUT AND THE WOOD MEMBER.

B. WOOD MEMBERS SHALL BE CONNECTED TOGETHER USING THE NAILING SCHEDULE UNLESS NOTED OTHERWISE. NO STAPLES ARE ALLOWED UNLESS NOTED OTHERWISE.

LOCATION	NAILING
TOP PLATE TO STUD, END-NAIL	2-16d
SOLE PLATE TO STUD, END-NAIL	2-16d, 4-8d TOE-NAIL
BUILT-UP STUDS	16d @ 24" CENTERS
DOUBLE TOP PLATE	16d @ 16" CENTERS
DOUBLE TOP PLATE SPLICE	8-16d
TRUSS TO NON-LOAD TOP PLATE	4-8d TOE-NAIL
DOUBLE HEADERS W/ 1/2" SPACER	16d @ 16" CENTERS EDGES
HEADER TO STUD, TOE-NAIL	4-8d EACH SIDE

C. ANCHORS TO FOUNDATION SHALL BE 1/2" DIA. ANCHOR BOLTS @ 48" CENTERS MAXIMUM. MINIMUM TWO ANCHOR BOLTS PER SILL BOARD WITH ONE ANCHOR BOLT WITHIN 12" OF EACH END OF EACH PIECE.

D. PLYWOOD DIAPHRAGMS AND SHEAR WALLS SHALL BE NAILED USING COMMON NAILS, SIZE AND SPACING SHOWN ON PLANS. SPECIAL PLYWOOD NAILS MAY BE SUBSTITUTED AS FOLLOWS:

10 GA. X 2" PLYWOOD NAILS FOR 8d COMMONS
9 GA. X 2 1/2" PLYWOOD NAILS FOR 10d COMMONS

4. PROVIDE BRIDGING AT 8'-0" CENTERS MAXIMUM FOR JOISTS AND RAFTERS USING 2X3 CROSS-BRIDGING OR SOLID BLOCKING.

6. WOOD HEADERS AND LINTELS SHALL BEAR ON TOP OF A SINGLE STUD AT EACH END FOR OPENINGS LESS THAN 3'-8", BEAR ON TOP OF DOUBLE STUDS FOR OPENINGS GREATER THAN 3'-8" AND LESS THAN 8'-0", AND TRIPLE STUDS FOR OPENINGS GREATER THAN 8'-0", UNLESS NOTED OTHERWISE. SUPPORT STUDS SHALL BE CONNECTED TO AN ADJACENT FULL LENGTH STUD.

(CONTINUED ON SHEET S2)

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.

Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.

Any substitutions of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrent the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever.

Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintainence thereof.

SHEET No.: S-1

DATE: 7 MARCH 2000

REVISED: | REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

WITCHITA SCHOOL TORNADO SHELTER

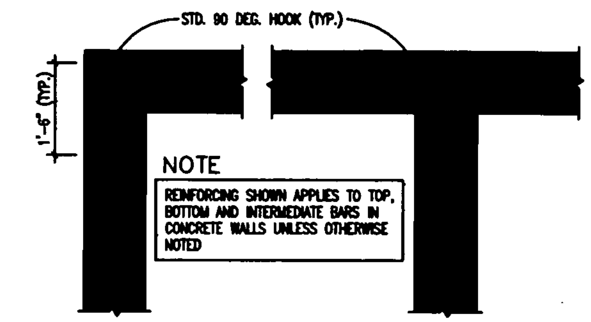
WICHITA, KANSAS

G. MISCELLANEOUS

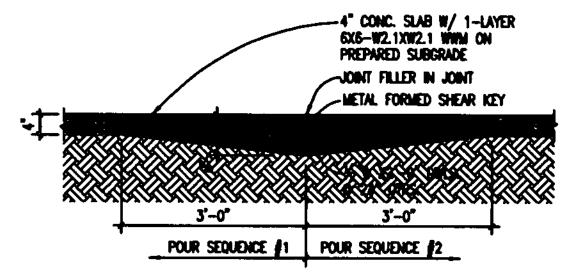
1. CONCRETE PADS FOR MECHANICAL AND ELECTRICAL EQUIPMENT ON FLOORS SHALL BE 3 1/2" HIGH UNLESS OTHERWISE NOTED AND REINFORCED WITH #3 BARS ON 12" CENTERS, EACH WAY, 1 1/2" FROM TOP OF SLAB. WHEN THE PAD EXCEEDS 10" IN THICKNESS, REINFORCE WITH #3 BARS ON 12" CENTERS EACH WAY, TOP AND BOTTOM. ANCHOR PAD TO SLAB WITH #4 DOWELS AT 24" CENTERS, EACH WAY, CAST OR EPOXIED INTO SUPPORTING SLAB.
2. CONTRACTOR SHALL SUPPLY ALL ITEMS FOR ATTACHING MECHANICAL AND ELECTRICAL EQUIPMENT TO THE BUILDING STRUCTURE TO RESIST ALL LOADS INCLUDING SEISMIC FORCES. ATTACHMENT SHALL BE MADE SO AS NOT TO OVERSTRESS STRUCTURAL MEMBERS. COORDINATE THE ATTACHMENTS AND LOCATIONS OF THE EQUIPMENT WITH THE STRUCTURAL SHOP DRAWINGS. REFER TO THE MECHANICAL AND ELECTRICAL DRAWINGS FOR ADDITIONAL REQUIREMENTS.
3. SUBSTITUTION OF EXPANSION ANCHORS FOR ADHESIVE ANCHORS, EPOXY ANCHORS OR EMBEDDED ANCHORS SHOWN ON THE DRAWINGS WILL NOT BE PERMITTED UNLESS APPROVED BY THE ENGINEER IN ADVANCE.
4. THE CONTRACTOR SHALL PROVIDE THE FOLLOWING ADDITIONAL SERVICES:
   A. VERIFICATION OF ALL DIMENSIONS, ELEVATIONS, OPENING SIZES, AND MECHANICAL EQUIPMENT WEIGHTS PRIOR TO STARTING WORK.
   B. REMOVE ALL ABANDONED FOUNDATIONS, UTILITIES, PIPELINES, ETC. THAT INTERFERE WITH NEW CONSTRUCTION.
   C. REVIEW AND APPROVE ALL SHOP DRAWINGS PRIOR TO SUBMITTAL, NOTING CHANGES MADE WHICH DO NOT COMPLY WITH DESIGN DRAWINGS.
   D. PROVIDE TEMPORARY BRACING AND SHORING TO PREVENT EXCESSIVE DEFLECTIONS AND DAMAGE DURING CONSTRUCTION. DESIGN OF TEMPORARY BRACING AND SHORING SHALL BE THE RESPONSIBILITY OF THE CONTRACTOR.

H. REQUIRED STRUCTURAL INSPECTIONS

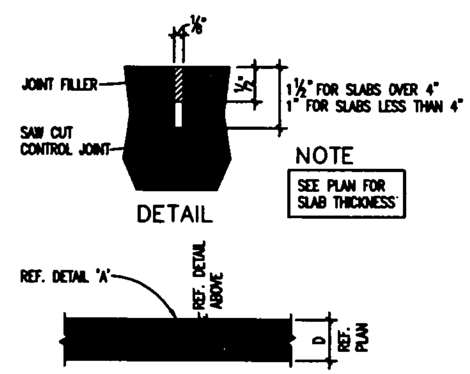
1. INSPECTIONS BY THE BUILDING OFFICIAL.
   A. FOUNDATION INSPECTION AFTER EXCAVATION AND SOIL PREPARATION, BUT PRIOR TO PLACING REINFORCING. AGAIN, AFTER REINFORCING PLACEMENT AND PRIOR TO CONCRETE PLACEMENT.
   B. CONCRETE SLAB ON GRADE/UNDERFLOOR INSPECTION SHALL BE MADE AFTER ALL UNDERFLOOR EQUIPMENT IS IN PLACE, BUT PRIOR TO CONCRETE PLACEMENT OR OTHER FLOORING PLACEMENT.
   C. FRAMING INSPECTION SHALL BE MADE AFTER ALL ROUGH MECHANICAL, ELECTRICAL, AND PLUMBING EQUIPMENT IS IN PLACE, BUT PRIOR TO FIREPROOFING OR WALL COVERING IS INSTALLED.
   D. FINAL INSPECTION SHALL BE MADE WHEN THE CONTRACTOR HAS COMPLETED THE BUILDING AND IT IS READY FOR OCCUPANCY.
2. IN ACCORDANCE WITH THE REQUIREMENTS OF THE BUILDING CODE, THE OWNER WILL PROVIDE QUALIFIED PERSONNEL TO PERFORM THE FOLLOWING SPECIAL INSPECTIONS AND REPORT THE FINDINGS TO THE ENGINEER. THIS DOES NOT RELIEVE THE CONTRACTOR OF ANY RESPONSIBILITY TO PERFORM THE WORK IN ACCORDANCE WITH THE DESIGN DRAWINGS. THE CONTRACTOR SHALL NOTIFY THE INSPECTOR 24 HOURS IN ADVANCE OF ALL INSPECTIONS.
   A. EXCAVATIONS, GRADING AND EARTH FILL SHALL BE INSPECTED IN ACCORDANCE WITH THE CODE.
   B. FOUNDATION INSPECTION DURING THE PLACEMENT OF PILING, DRILLED PIERS, GRADE BEAMS, FOOTINGS, RETAINING WALLS, AND SLABS ON GRADE. ALL EMBEDDED BOLTS SHALL BE INSPECTED.
   C. FRAMING INSPECTIONS DURING THE ERECTION OF ALL STEEL FRAMING MEMBERS. INSPECTIONS OF ALL DECKING PLACEMENT AND ATTACHMENTS.
   D. DUCTILE-MOMENT RESISTING STEEL FRAMES SHALL HAVE WELDS INSPECTED IN ACCORDANCE WITH THE CODE.
   E. HIGH-STRENGTH BOLTS SHALL BE INSPECTED DURING INSTALLATION AND TIGHTENING IN ACCORDANCE WITH THE CODE.
   F. ALL REINFORCING STEEL SHALL BE INSPECTED PRIOR TO CONCRETE PLACEMENT. ALL PRESTRESSING SHALL BE INSPECTED DURING STRESSING AND DURING GROUTING.
   H. DUCTILE MOMENT-RESISTING CONCRETE FRAMES AS REQUIRED IN THE CONCRETE CODE.
   I. STRUCTURAL MASONRY SHALL BE INSPECTED DURING PLACEMENT IN ACCORDANCE WITH THE CODE.
   J. SPRAY-APPLIED FIREPROOFING INSPECTIONS SHALL BE MADE IN ACCORDANCE WITH THE CODE.



1 TYP. CORNER AND INTERSECTION REINF.
NO SCALE



2 SLAB CONSTRUCTION JOINT (CJ)
3/4"=1'-0"



3 TYPICAL SLAB SAWN JOINT (SJ)
NO SCALE

TABLE A – REINFORCEMENT TENSION LAPS, EMBEDMENT AND HOOK LENGTHS (1)
fy = 60000 psi f'c = 3000 psi (2) (3)

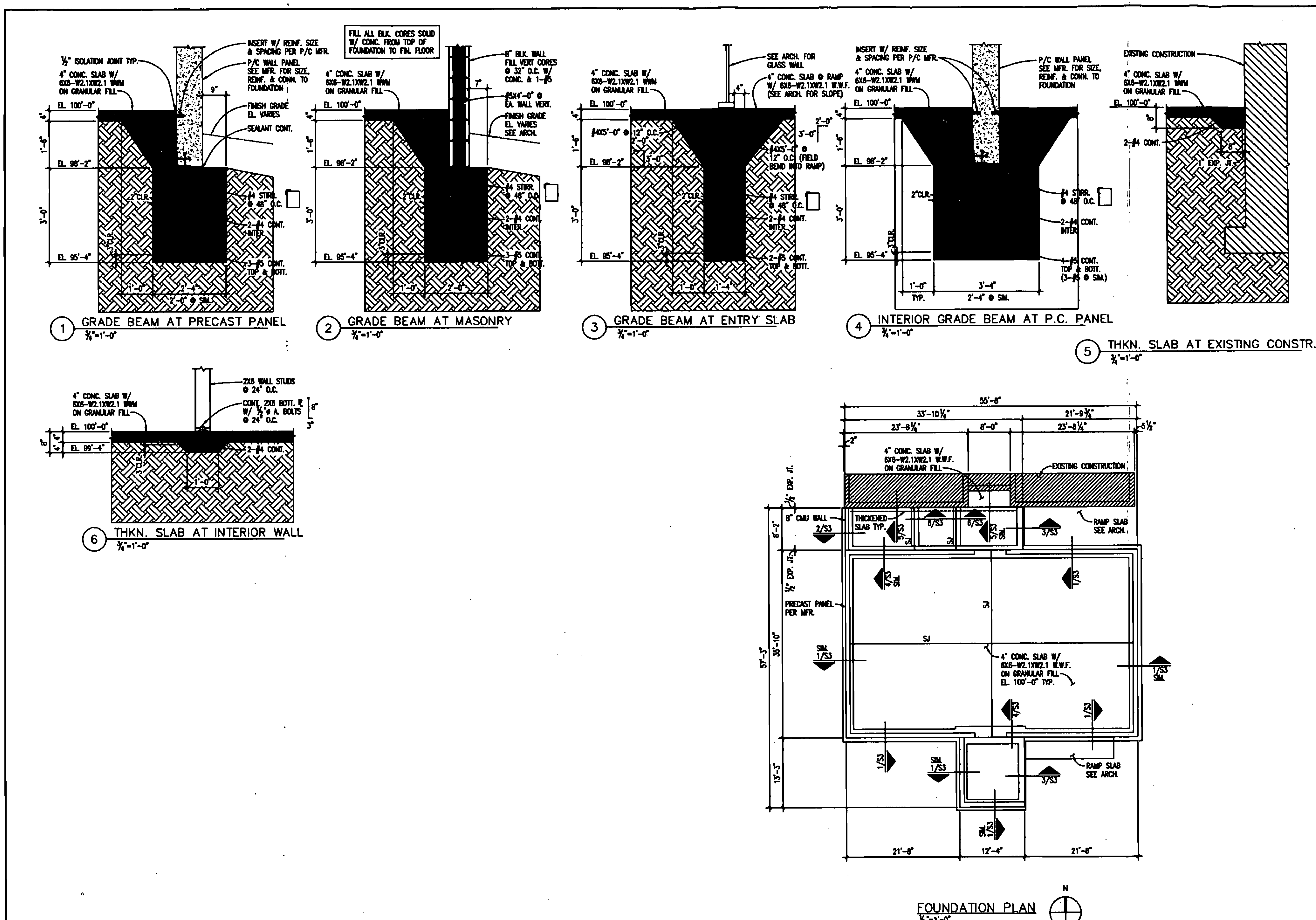
BAR SIZE (d)	CLEAR SPACING (S) (in) (4)			EMBEDMENT & CLASS A LAP (in) (5)(6)(7)						CLASS B LAP (in) (6)(8)						HOOK (in) (9)
				TOP BAR (10)			OTHER BARS			TOP BAR (10)			OTHER BARS			
	2d	3d	5d	2d<S<3d	S≥3d (11)	S≥5d (12)	2d<S<3d	S≥3d (11)	S≥5d (12)	2d<S<3d	S≥3d (11)	S≥5d (12)	2d<S<3d	S≥3d (11)	S≥5d (12)	
3	3/4	1 1/8	1 7/8	16	16	16	13	13	13	21	21	21	16	16	16	9
4	1	1 1/2	2 1/2	22	22	22	17	17	17	28	28	28	22	22	22	11
5	1 1/4	1 7/8	3 1/8	27	27	27	21	21	21	35	35	35	27	27	27	14
6	1 1/2	2 1/4	3 3/4	35	32	32	27	25	25	46	42	42	35	32	32	17
7	1 3/4	2 5/8	4 3/8	48	38	38	37	29	29	63	49	49	48	38	38	20
8	2	3	5	63	45	43	49	35	33	82	59	56	63	45	43	22
9	2 1/4	3 3/8	5 5/8	80	57	48	62	44	37	104	74	63	80	57	48	25
10	2.54	3.81	6.35	102	73	58	78	56	45	132	94	76	102	73	58	28
11	2.82	4.23	7.05	125	89	71	96	69	55	162	116	93	125	89	71	31

NOTES FOR USE WITH TABLE A

1. LENGTHS SHOWN CONFORM WITH NON-SEISMIC PROVISIONS OF ACI 318-89 FOR UNCOATED BARS NOT ENCLOSED BY CLOSELY SPACED SPIRALS OR TIES. DEVELOPMENT OF REINFORCEMENT NOT COVERED BY THE TABLE SHALL CONFORM WITH ACI 218-89.
2. MULTIPLY LENGTHS SHOWN BY 0.87 FOR 4000 PSI CONCRETE, BUT LENGTH OF LAP SHALL NOT BE LESS THAN 12 INCHES.
3. MULTIPLY LENGTHS SHOWN BY 1.3 FOR LIGHTWEIGHT AGGREGATE CONCRETE.
4. BAR CLEAR SPACING IS THE CENTER TO CENTER BAR SPACING MINUS TWO BAR DIAMETERS WHEN ALL BARS ARE LAPPED AT THE SAME LOCATION. WHEN BAR LAPS ARE STAGGERED TO LAP HALF THE BARS AT THE SAME LOCATION, THE BAR CLEAR SPACING IS TWICE THE CENTER TO CENTER BAR SPACING MINUS TWO BAR DIAMETERS. WHEN ALL BARS ARE EMBEDDED AT THE SAME LOCATION, THE BAR CLEAR SPACING IS THE CENTER TO CENTER BAR SPACING MINUS ONE BAR DIAMETER.
5. CLASS A LAP LENGTHS APPLY WHEN BAR LAPS ARE STAGGERED TO LAP HALF THE BARS AT THE SAME LOCATION OR WHEN BARS ARE LAPPED AT A LOCATION OF MINIMUM STRESS IN THE BARS.
6. LAP AND EMBEDMENT LENGTHS SHOWN APPLY WHEN BAR MINIMUM CONCRETE COVER OVER BARS CONFORMS WITH VALUES GIVEN IN THE TABLE FOR "CONCRETE COVER". THESE COVER VALUES CONFORM WITH ACI 318-89.
7. CLASS A LAP AND EMBEDMENT LENGTH HAVE SAME VALUE.
8. CLASS B LAP LENGTHS APPLY WHEN ALL BARS ARE SPLICED AT A LOCATION OF MAXIMUM STRESS IN THE BARS.
9. HOOK LENGTH GIVEN IS THE STRAIGHT LINE DISTANCE FROM THE LOCATION OF MAXIMUM STRESS IN THE BAR TO THE OUTSIDE END OF THE HOOK. MULTIPLY LENGTHS GIVEN BY 0.7 FOR HOOKS WITH SIDE COVER NORMAL TO THE HOOK NOT LESS THAN 2 1/2 INCHES AND FOR 90 DEGREE HOOKS COVER ON BAR EXTENSION BEYOND HOOK NOT LESS THAN 2 INCHES.
10. TOP BARS ARE HORIZONTAL REINFORCEMENT PLACED SO THAT MORE THAN 12 INCHES OF CONCRETE IS CAST BELOW THE REINFORCEMENT.
11. MULTIPLY LAP AND EMBEDMENT LENGTHS GIVEN BY 2.0 FOR BARS WITH CLEAR SPACING OF TWO BAR DIAMETERS OR LESS, OR CONCRETE COVER OF ONE BAR DIAMETER OR LESS.
12. MINIMUM CONCRETE COVER FROM FACE OF MEMBER TO EDGE BAR SHALL NOT BE LESS THAN TWO AND ONE HALF BAR DIAMETERS.

SHEET No.: S-2
DATE: 7 MARCH 2000
REVISED: | REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC



BEST COPY AVAILABLE

WITCHITA SCHOOL TORNADO SHELTER

WICHITA, KANSAS

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.

Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.

Any substitutions of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

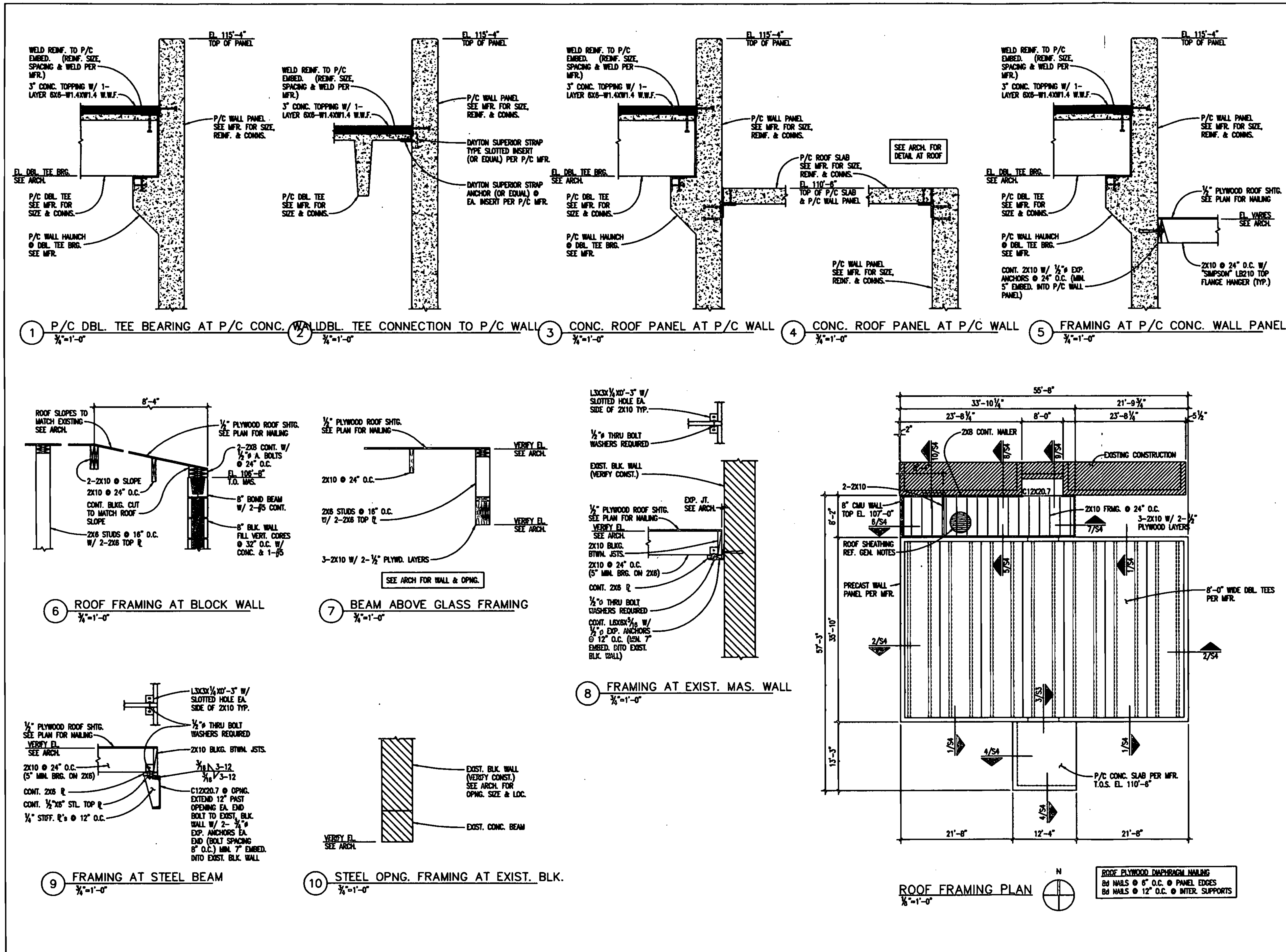
Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever.

Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintainence thereof.

SHEET No.: S-3
DATE: 7 MARCH 2000
REVISED: REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY MITIGATION DIRECTORATE WASHINGTON, DC



WITCHITA SCHOOL TORNADO SHELTER

WICHITA, KANSAS

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.

Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.

Any substitutions of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever.

Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintainance thereof.

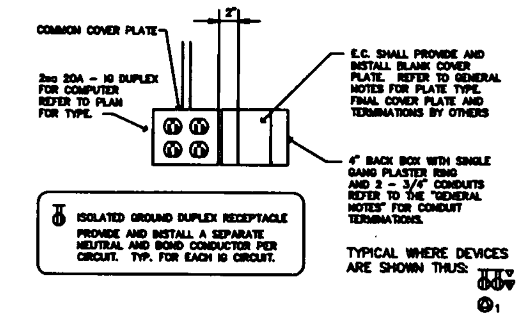
SHEET No.: S-4	
DATE: 7 MARCH 2000	
REVISED:	REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

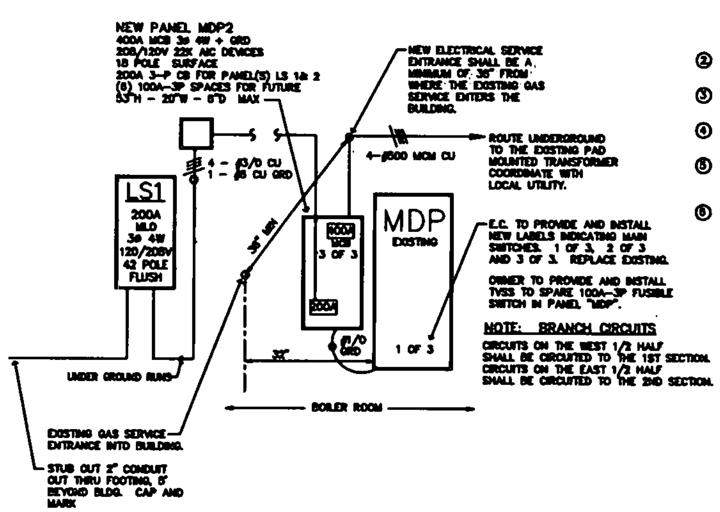
BEST COPY AVAILABLE

GENERAL NOTES

1. ALL WORK SHALL COMPLY WITH LOCAL, STATE AND NATIONAL CODES.
2. THE ELECTRICAL CONTRACTOR SHALL SECURE AND PAY FOR ALL PERMITS, FEES, INSPECTIONS AND CERTIFICATES REQUIRED.
3. THE ELECTRICAL CONTRACTOR SHALL FURNISH ALL LABOR, MATERIAL, TOOLS, TRANSPORTATION, AND EQUIPMENT REQUIRED FOR THE COMPLETE, PROPER AND SUBSTANTIAL INSTALLATION OF ALL ELECTRICAL WORK INDICATED OR REQUIRED FOR A COMPLETE WORKING INSTALLATION OF ALL ELECTRICAL SYSTEMS.
4. REFER TO ARCHITECTURAL, STRUCTURAL AND MECHANICAL PLANS FOR RELATED INFORMATION.
5. REFER TO MECHANICAL PLANS AND SPECIFICATIONS FOR EXACT LOCATION OF MECHANICAL EQUIPMENT AND T-STAT LOCATIONS. FUSING OF MECHANICAL EQUIPMENT AS PER NAME PLATE DATA ON EQUIPMENT.
6. ALL LINE VOLTAGE WIRING SHALL BE COPPER IN STEEL CONDUIT & STEEL BOXES, UNLESS SPECIFICALLY NOTED OTHERWISE. EACH CONDUIT CONTAINING LINE VOLTAGE SHALL CONTAIN A GREEN, INSULATED GROUND CONDUCTOR. ALL CONDUITS ROUTING SHALL BE INSTALLED PARALLEL AND PERPENDICULAR. ALL CONDUIT PENETRATIONS OF FIRE RATED WALLS SHALL BE SEALED WITH A APPROPRIATELY RATED FIRE STOP MATERIAL.
7. STRAIGHT RUNS UNDERGROUND / IN SLAB CONDUIT MAY BE SCHEDULE 40 PVC, 3/4" MINIMUM WITH STEEL ELLS, BENDS AND RISERS. ALL RISERS PENETRATING SLAB OR EXITING FROM EARTH SHALL BE RIGID STEEL. NO EXCEPTIONS.
8. ALL CONDUITS STUBBED OUT OF BUILDING, SHALL BE CAPPED AND MARKED.
9. ALL CONDUITS STUBBED INTO THE CEILING CAVITY FOR MECHANICAL CONTROLS, FIRE ALARM, DATA, COMMUNICATIONS, TELEVISION, CLOCKS, INTERCOM, ETC. SHALL BE PROVIDED WITH A PRESS ON, INSULATING BUSHING. ARLINGTON INDUSTRIES # EMT SERIES OR EQUAL.
10. VERIFY ALL OUTLET LOCATIONS ON JOB, PRIOR TO ROUGH-IN.
11. EXTERIOR EXPOSED CONDUIT RUNS WILL NOT BE PERMITTED. (EXCEPT FOR SERVICE ENTRANCES POWER/TELEPHONE OR NOTED OTHERWISE ON PLAN.)
12. REFER TO ARCHITECTURAL PLANS/SPECIFICATIONS FOR A DETAILED DESCRIPTION OF ALL ALTERNATES. ELECTRICAL WORK MAY BE INVOLVED THAT DOES NOT SHOW ON THE ELECTRICAL PLANS.
13. ALL NEW CONDUIT SHALL BE INSTALLED CONCEALED INSIDE CONSTRUCTION. ANY NEW SURFACE MOUNTED RACEWAYS, IN FINISHED AREAS, SHALL BE APPROVED IN WRITING BY THE ARCHITECT PRIOR TO INSTALLATION. NO EXCEPTIONS. SURFACE MOUNTED RACEWAY IN NON-SHOP FINISHED AREAS SHALL BE WIREMOLD #500/700 RACEWAY. RUNS SHALL BE PARALLEL/PERPENDICULAR TO STRUCTURE. FASTEN TO WALLS (ANCHORS IN SOLID WALLS / TOGGLE ANCHORS IN HOLLOW WALLS) EVERY 36". E.C. RESPONSIBLE FOR PAINTING RACEWAYS TO MATCH SURROUNDINGS, EITHER FOR EXISTING AREAS AND/OR NEW CONSTRUCTION. EMT CONDUIT IS ACCEPTABLE INSIDE NEW SHOP/CLASS ROOM AREA.
14. E.C. SHALL VISIT SITE TO DETERMINE : 1.) EXISTING CONDITIONS. 2.) THE EXTENT OF DEMOLITION. ANY CONFLICTS BETWEEN PLANS/SPECIFICATIONS AND ACTUAL EXISTING CONDITIONS THAT AFFECT CONSTRUCTABILITY, SHALL BE BROUGHT TO THE ATTENTION OF THE ENGINEER PRIOR TO BID. NO EXCEPTIONS.
15. ALL PANELS SHALL BE PANELBOARD CONSTRUCTION WITH BOLT-IN CIRCUIT BREAKERS, COPPER BUS AND COPPER GROUND BUS.
15. TELEPHONE OUTLETS: ◀
EMPTY 4" SQUARE BOX WITH A SINGLE GANG PLASTER RING AND BLANK PLATE. PROVIDE 3/4" C. WITH PULL WIRE FROM OUTLET TO ABOVE ACCESSIBLE CEILING. CONDUCTORS, CONDUCTOR INSTALLATION AND TERMINATIONS NOT IN CONTRACT.
16. CRT/DATA OUTLETS: ▽
EMPTY 4" SQUARE BOX WITH A SINGLE GANG PLASTER RING AND BLANK PLATE. PROVIDE 3/4" C. WITH PULL WIRE FROM OUTLET TO ABOVE ACCESSIBLE CEILING. CONDUCTORS, CONDUCTOR INSTALLATION AND TERMINATIONS NOT IN CONTRACT.
17. COLOR OF DEVICES/PLATES: MATCH EXISTING
TYPE OF PLATES: MATCH EXISTING
18. MECHANICAL/TEMPERATURE CONTROL WIRING NEED NOT BE INSTALLED IN CONDUIT ABOVE ACCESSIBLE CEILINGS, UNLESS SPECIFICALLY NOTED OTHERWISE. REFER TO THE MECHANICAL PLANS AND SPECIFICATIONS. CONDUIT IS REQUIRED FOR VERTICAL RUNS IN WALLS AND WHERE EXPOSED. ALL CONDUIT REQUIRED, SHALL BE PROVIDED AND INSTALL BY THE E.C. REQUIRED CONDUCTORS AS FOLLOWS:
    1. ALL LINE VOLTAGE SUPPLY (CONSTANT) POWER WIRING SHALL BE PROVIDED AND INSTALLED, IN CONDUIT, BY THE E.C.
    2. ALL LOW AND LINE VOLTAGE CONTROL (SWITCHED) WIRING, WIRING INSTALLATION AND TERMINATIONS SHALL BE PROVIDED AND INSTALLED BY THE M.C./T.C.C (LINE VOLTAGE CONTROL WIRING SHALL BE INSTALLED IN CONDUIT. CONDUIT FOR LINE VOLTAGE CONTROL WIRING - BY E.C.)
    2. N.E.C ART 300-11(B): RACEWAYS SHALL NOT BE USED AS A MEANS OF SUPPORT FOR CABLES OR NONELECTRICAL EQUIPMENT.
19. "BACK TO BACK" MOUNTING OF DEVICES IN WALLS IS NOT ALLOWED. MINIMUM OF ONE STUD SPACE BETWEEN DEVICES.
20. E.C. IS RESPONSIBLE FOR THE RELOCATION OF ALL ELECTRICAL DEVICES, EXISTING OR NEW, DUE TO ANY ARCHITECTURAL MODIFICATIONS. REFER TO THE ARCHITECTURAL PLANS, SPECIFICATIONS AND ADDENDA FOR: NEW DOOR LOCATIONS, WALL REMOVAL, WALL ADDITIONS, CEILING MODIFICATIONS, ETC.
21. REFER TO THE ARCHITECTURAL PLANS/SPECIFICATIONS FOR A COMPLETE, DETAILED LIST OF ALL ALTERNATES.
22. THE MOUNTING HEIGHTS OF THE ELECTRICAL DEVICES ARE TO THE CENTER OF THE DEVICE. REFER TO THE SYMBOL LIST. SPECIAL MOUNTING HEIGHTS ARE SHOWN ADJACENT TO THE DEVICE. ALL MOUNTING HEIGHTS LISTED ARE FROM ABOVE FINISHED FLOOR. (AFF)
EXCEPTION:
E.C. SHALL COORDINATE THE MOUNTING OF FLUSH MOUNTED DEVICES IN MASONRY BLOCK WALLS WITH THE MASONRY CONTRACTOR. MOUNTING HEIGHTS WILL BE DETERMINED BY ACTUAL BLOCK CONFIGURATION. MOUNT DEVICES SUCH THAT THE EDGE OF THE COVER PLATE IS EVEN WITH THE TOP OR BOTTOM OF THE BLOCK. DO NOT OVERLAP JOINT. MOUNT DEVICES IN A SINGLE BLOCK.
23. E.C. SHALL PROVIDE AND INSTALL A SINGLE GANG BOX, 40" AFF WITH 1/2" CONDUIT TO ABOVE ACCESSIBLE CEILING FOR T-STATS. REFER TO THE MECHANICAL PLANS FOR PLACEMENT OF T-STATS.
24. REFER TO THE MECHANICAL ADDENDA FOR THE ADDITION, DELETION OR REVISION OF MECHANICAL EQUIPMENT.
25. DO NOT MOUNT DISCONNECT SWITCHES ON ACCESSIBLE PANELS FOR RTU'S, AHU'S, ETC. E.C. SHALL PROVIDE AND INSTALL PROPER SUPPORTS TO MOUNT SWITCH, CLEAR OF ALL ACCESSIBLE PANELS.
26. REFER TO THE ARCHITECTURAL PLANS FOR THE EXTENT OF ALL DEMOLITION.
29. E.C IS RESPONSIBLE FOR RETAINING THE CONTINUITY OF EACH EXISTING BRANCH CIRCUIT. SPECIAL ATTENTION SHALL BE GIVEN TO THOSE CIRCUITS WHICH WILL BE ALTERED DUE TO THE DEMOLITION AND/OR NEW CONSTRUCTION.
28. E.C. SHALL COORDINATE ANY "DOWN TIME" OF ANY SYSTEM WITH THE OWNER. THIS INCLUDES BUT NOT LIMITED TO: EMERGENCY LIGHTING, FIRE ALARM SYSTEM, COMMUNICATION SYSTEM, DATA SYSTEM, NORMAL POWER, ETC. E.C. SHALL INFORM OWNER, IN WRITING, 5 WORKING DAYS PRIOR TO "SCHEDULED SHUT-DOWNS". LIFE SAFETY SYSTEMS SUCH AS FIRE ALARM AND EMERGENCY LIGHTING MUST REMAIN ACTIVE AT ALL TIMES WHEN THE SPACE IS OCCUPIED.
29. EACH BRANCH CIRCUIT SHALL HAVE IT'S OWN SEPARATE NEUTRAL. DO NOT COMBINE MULTIPLE BRANCH CIRCUITS WITH A COMMON NETURAL.



WORK STATION DETAIL



DISTRIBUTION DIAGRAM

E.C SHALL VISIT SITE TO VERIFY ACTUAL CONDITIONS AND CONDUIT ROUTING

LIGHT FIXTURE SCHEDULE

	MFG. & CATALOG NUMBER	VOLT	LAMPS	MOUNTING
A	LITHONIA # 8TLB332-120ES ⑤⑥	120	3 - F032/741	18" STEM SET
B	WILLIAMS # 50G-S24-2320C-SWKA125-ETB ⑤①	120	2 - F032/741	TROFFER
C	LITHONIA # TWH-70S-120 ④	120	1 - LU70	WALL @ 12'
D	LITHONIA # TWH-100S-120	120	1 - LU100	WALL @ 12'
F	PATTON # 989W WHITE 3 SPEED/REVERSIBLE	120	NONE	36" PENDANT
	SURE-LITE # CAX-7-1/2-70-R-120/277 ①	③	FURNISHED W/UNIT	CEILING
	SURE-LITE # CAX-7-1/2-70-R-120/277 ①	③	FURNISHED W/UNIT	WALL
	SURE-LITE # RD-3 (MINI HEADS)		FURNISHED W/UNIT	RECESSED CLG
	SURE-LITE # XR11-215 (WG = WIRE GUARD)		FURNISHED W/UNIT	WALL

① SPECIFICATION GRADE TROFFER EQUALS:
WILLIAMS SERIES 50, LITHONIA SERIES 2SP-APAF, METALUX SERIES 2GC, COLUMBIA SERIES 4000-PAF
ENTIRE FIXTURE SHALL BE POST PAINTED INCLUDING SOCKET RAILS, BALLAST COVER, END PLATES, DOOR FRAME, ETC. LENS: .125 NOMINAL THICK EQUAL TO KSH-12.

EXIT SIGN EQUALS:
PRESCOLITE "COMPASS" SERIES
LITHONIA " SIGNATURE" SERIES

ALL SUBSTITUTIONS SHALL BE REVIEWED AT SHOP DRAWINGS FOR ACCEPTANCE OR REJECTION. ATTENTION SHALL BE GIVEN TO LAMPS, VOLTAGE, MOUNTING, PHYSICAL DIMENSIONS, FINISHES, PHOTOMETRICS, ETC.

② SURFACE MOUNTED FIXTURES MOUNTED TO A "T" BAR CEILING GRID SHALL BE FASTENED TO THE GRID IN FOUR PLACES TO INSURE RIGID SUPPORT.

③ CONNECT TO UNSWITCHED LEG OF LOCAL AREA LIGHTING CIRCUIT. REFER TO THE LIGHTING PLANS FOR EXIT, SIGN FACE AND ARROW DIRECTIONS. 120/277 VOLT. PROVIDE BATTERY FOR EXITS AND EGRESS FIXTURES.

④ ALL HID FIXTURES SHALL BE "BURNED-IN" AS PER LAMP MANUFACTURER'S RECOMMENDATIONS TO INSURE PROPER LAMP LIFE.

⑤ ALL FLUORESCENT FIXTURES SHALL BE SUPPLIED WITH INSTANT START, 20K HZ ELECTRONIC BALLAST(S). ACCEPTED BALLASTS: MOTOROLA/GE O-IN SERIES, ADVANCE REL/VEL: P SERIES, EQUAL BY SYLVANIA AND UNIVERSAL. BALLASTS SHALL BE COMPATIBLE WITH LAMPS.

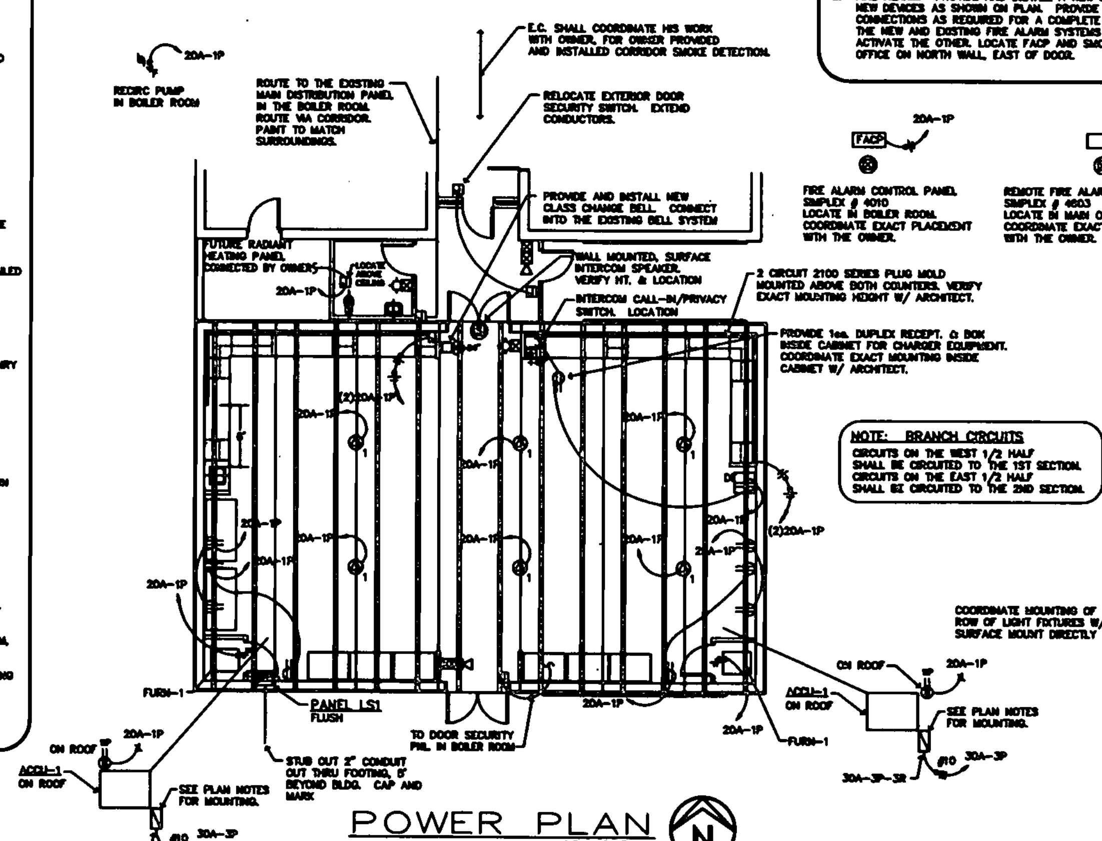
⑥ FIXTURES DESIGNATED "a,b" SHALL BE SWITCHED FOR DUAL LEVEL ILLUMINATION. OUTBOARD LAMPS SEPARATE FROM INBOARD LAMPS.
E.C. OPTION: MASTER / SLAVE FIXTURES (CONSIDER ODD NUMBER OF FIXTURES WITHIN AN AREA) OR PROVIDE EACH FIXTURE WITH 2 BALLASTS.

SCOPE OF WORK

1. INTERCOM SYSTEM: E.C. SHALL PROVIDE CONDUIT, BOXES AND WIRING FOR THE NEW INTERCOM EQUIPMENT. DEEP WIREMOLD BOX FOR THE CALL-IN SWITCH. SHALLOW WIREMOLD BOX FOR THE SPEAKER. WIRING FROM THE NEW CLASSROOM TO THE EXISTING MASTER INTERCOM IN THE OFFICE AREA. USE EXISTING INTERCOM RACEWAYS WHERE POSSIBLE. ALLOW 36" OF CONDUCTORS AT TERMINATION POINTS FOR OWNER CONNECTIONS. OWNER SHALL PROVIDE AND INSTALL: CALL-IN/PRIVACY SWITCH, SURFACE SPEAKER, AND CONNECTIONS TO MASTER.
2. SECURITY SYSTEM: E.C. SHALL RELOCATE DOOR SWITCH FROM THE EXISTING SOUTH EXTERIOR DOOR TO THE NEW EAST EXTERIOR DOOR. (APPROX 10' TO THE N.E.) E.C. TO PROVIDE AND INSTALL J-BOX, CONDUIT/WIREMOLD, AND CONDUCTORS FROM THE NEW SET OF DOUBLE DOORS (SOUTH) TO THE EXISTING SECURITY PANEL IN THE BOILER ROOM. ALLOW 36" OF CONDUCTORS AT TERMINATION POINTS FOR OWNER CONNECTIONS. VERIFY CONDUCTOR TYPE W/ OWNER. OWNER SHALL PROVIDE AND INSTALL: SECURITY DEVICES AND CONNECTIONS.
3. FIRE ALARM: PROVIDE AND INSTALL A NEW SIMPLEX 4010 FACP AND NECESSARY NEW DEVICES AS SHOWN ON PLAN. PROVIDE AND INSTALL NECESSARY WIRING AND CONNECTIONS AS REQUIRED FOR A COMPLETE AND OPERATIONAL SYSTEM. CONNECT THE NEW AND EXISTING FIRE ALARM SYSTEMS TOGETHER. EITHER SYSTEM SHALL ACTIVATE THE OTHER. LOCATE FACP AND SMOKE DETECTOR IN THE PRINCIPALS OFFICE ON NORTH WALL EAST OF DOOR.

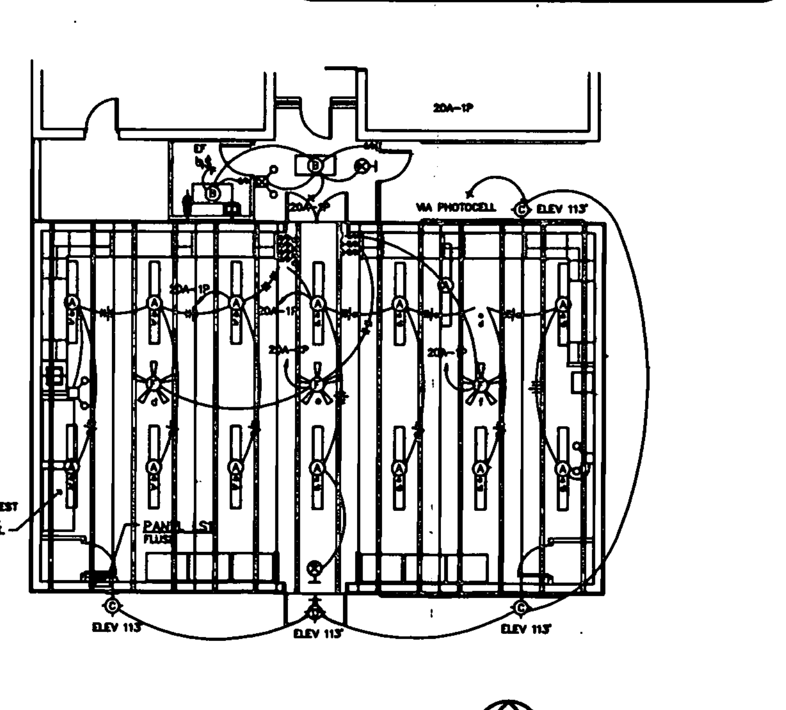
SYMBOL LIST

SYMBOL	DESCRIPTION	MOUNTING
AFF	ABOVE FINISHED FLOOR	
CT	MOUNTED ABOVE COUNTER TOP	VERIFY HT.
EM	CONNECTED TO EMERGENCY POWER	
NL	NIGHTLIGHT, WIRE FOR CONTINUOUS OPERATION	
WP	WEATHER PROOF	
3R	NEMA 3R ENCLOSURE	
TTB	TELEPHONE TERMINAL BOARD	
a,b,c,d	SWITCH DESIGNATION (LIGHTS, FANS ETC.)	
E.C. M.C. G.C. T.C.C	ELECTRICAL CONTRACTOR, MECHANICAL CONTRACTOR GENERAL CONTRACTOR, TEMP. CONTROL CONTRACTOR	
\$, \$3, \$4, \$P, \$K	SWITCHES (2-POLE, 3-WAY, 4-WAY, PILOT, KEY)	4'-0" AFF
	FUSTAT IN BUSS FUSETRON BOX COVER UNIT W/ SW.	ON EQUIPMENT
	MOTOR SPEED CONTROL , SIZE AS INDICATED	4'-0" AFF
	WORK STATION - SEE DETAIL	1'-4" AFF
	20 A. 125 V. IG DUPLEX RECEPTACLE FOR COMPUTER HUBBELL # IG 5362 ORANGE. SEPARATE NEUTRAL AND BOND CONDUCTORS PER CIRCUIT. IG CONDUCTORS IN SEPARATE RACEWAY SYSTEM.	1'-4" AFF
	20 A. 125 V. DUPLEX GROUNDED RECEPTACLE	1'-4" AFF
	20 A. 125 V. DUPLEX GFI RECEPTACLE - 5 mA FEED THRU PROTECTION TO NORMAL RECEPTACLES IS NOT ACCEPTABLE.	1'-4" AFF
	20 A. 125V. 1/2 SWITCHED DUPLEX RECEPTACLE	1'-4" AFF
	20 A. 125 V. DOUBLE DUPLEX GROUNDED RECEPTACLE	1'-4" AFF
DF	20 A. 125 V. SINGLE DUPLEX GROUNDED RECEPTACLE FOR DRINKING FOUNTAIN. CONCEAL BEHIND FOUNTAIN	HORIZONTAL
	15 A. 125 V. CLOCK RECEPTACLE	6'-6" AFF
	MOTOR	
	JUNCTION BOX	
	SPECIAL DEVICE AS NOTED	
	CONDUIT RUN 1/2" CONDUIT	WALL, CEILING
	CONDUIT RUN 3/4" CONDUIT MINIMUM	FLOOR, EARTH
	CONDUIT RUN W/ 3 HOTS, 1 NEUTRAL, & 1 GROUND	
	TO PANEL - CIRCUIT AS INDICATED (20A.-1P. BREAKER UNLESS OTHERWISE INDICATED)	
	PARTIAL CIRCUIT	
	120/208 V. 3ø 4W. CIRCUIT BREAKER PANELBOARD	6'-0" TO TOP
	FUSED DISCONNECT SWITCH - HEAVY DUTY	
	MAGNETIC MOTOR STARTER	6'-0" TO TOP
A	FLUORESCENT FIXTURE - AND FIXTURE DESIGNATION	CEILING
	SEE WORKSTATION DETAIL, THIS SHEET.	
	FIRE ALARM MANUAL PULL STATION	4'-0" AFF
	FIRE ALARM UNIT - COMBINATION AUDIO/VISUAL 80"AFF OR 6" BELOW THE CEILING WHICHEVER IS LOWER. 30/110 cd	AS PER ADA
	FIRE ALARM UNIT - STROBE ONLY 80"AFF OR 6" BELOW THE CEILING WHICHEVER IS LOWER. 30/110 cd	AS PER ADA
FACP	FIRE ALARM CONTROL PANEL - SIMPLEX 4010	



POWER PLAN

SCALE: 1/8" = 1'-0"



LIGHTING PLAN

SCALE: 1/8" = 1'-0"

WITCHITA SCHOOL TORNADO SHELTER

WICHITA, KANSAS

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.

Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.

Any substitutions of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever.

Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

SHEET No.: E-1	
DATE: 7 MARCH 2000	
REVISED:	REV. NO.

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

BEST COPY AVAILABLE

WITCHITA SCHOOL TORNADO SHELTER

WICHITA, KANSAS

SYMBOL SCHEDULE

MARK	DESCRIPTION	MARK	DESCRIPTION	MARK	DESCRIPTION
	WASTE PIPING (W)		AIR VENT	FSD	FIRE & SMOKE DPR
—CD—	CONDENSATE DRAIN (CD)		BALL VALVE	CRD	CEILING RADIATION DAMPER
—RLP—	RAIN LEADER PIPING	F.D.	FLOOR DRAIN	RAG	RETURN AIR GRILLE
	COLD WATER PIPING (CW)	VTR	VENT THRU ROOF	WPL	WEATHERPROOF LOUVER
	HOT WATER PIPING (HW)			SR	SUPPLY REGISTER
	HOT WATER RECIRCULATING PIPING			ER	EXHAUST REGISTER
	PLUMBING VENT (V)	M.C.	MECHANICAL CONTRACTOR	EG	EXHAUST GRILLE
—G—	GAS PIPING	G.C.	GENERAL CONTRACTOR	CD	CEILING DIFFUSER
	GATE VALVE	E.C.	ELECTRICAL CONTRACTOR	T	THERMOSTAT
	CHECK VALVE		SUPPLY AIR DUCT	TN	NIGHT THERMOSTAT
	BALANCING VALVE		RETURN AIR DUCT	T	OVERRIDE TIMER
	GAS COCK		FRESH AIR DUCT		
	UNION		EXHAUST AIR DUCT		
W.H.	WALL HYDRANT		FIRE DAMPER (F.DR.)		
C.O.	CLEANOUT		MANUAL DAMPER (MD)		

NOTE:

PLUMBING FIXTURE SCHEDULE

MARK	FIXTURE	COLD WATER	HOT WATER	WASTE	VENT	
P-1	HC WATER CLOSET	1"	—	4"	2"	
P-2	HC LAVATORY	1"	1"	1½"	1½"	
P-3	SINK	1"	1"	1½"	1½"	
P-4	HC DRINKING FOUNTAIN	1"	—	1½"	1½"	

NOTE:

EVAPORATOR COIL SCHEDULE

MARK	CFM	COOLING BTUH @ ARI	MIN. ROWS	FACE AREA	REFRIG. SUCTION	REFRIG. LIQUID	CONDENSATE DRAIN	USED WITH	MAX. S.P.	REMARKS
EC-1	1450	43,500	3	5.50	1" OD	1" OD	1"	FURN-1	0.25"	

NOTE: MUST BE ARI LISTED W/ACCU FURNISHED

FURNACE SCHEDULE

MARK	CFM	EXT. S.P.	BTUH @ AGA INPUT	OUTPUT	REQ'D MIN*	BLOWER MOTOR H.P.	R.P.M.	CURRENT	FLUE SIZE	FILTERS TYPE	MIN. SIZE	GAS CONN.	O.A. CFM	REMARKS
FURN-1	1450	0.5"	80,000	75,000	65,000	1/3	1075	115/60/1ϕ	2"ϕ PVC	TA	20x25x2	3/4"	225	

NOTE: * OUTPUT

AIR COOLED CONDENSING UNIT SCHEDULE

MARK	TOTAL BTUH CLG @ ARI	REQ'D MIN TOTAL BTUH CLG @ ARI	COMPRESSOR F.L.A.	COMPRESSOR CURRENT	CONDENSER FAN AMPS	SEER	MIN. CIRCUIT AMPS	REC. FUSE SIZE	REMARKS
ACCU-1	43,500	43,000	14.9	208/60/3ϕ	1.7	10.05	20	30	

NOTE:

EXHAUST FAN SCHEDULE

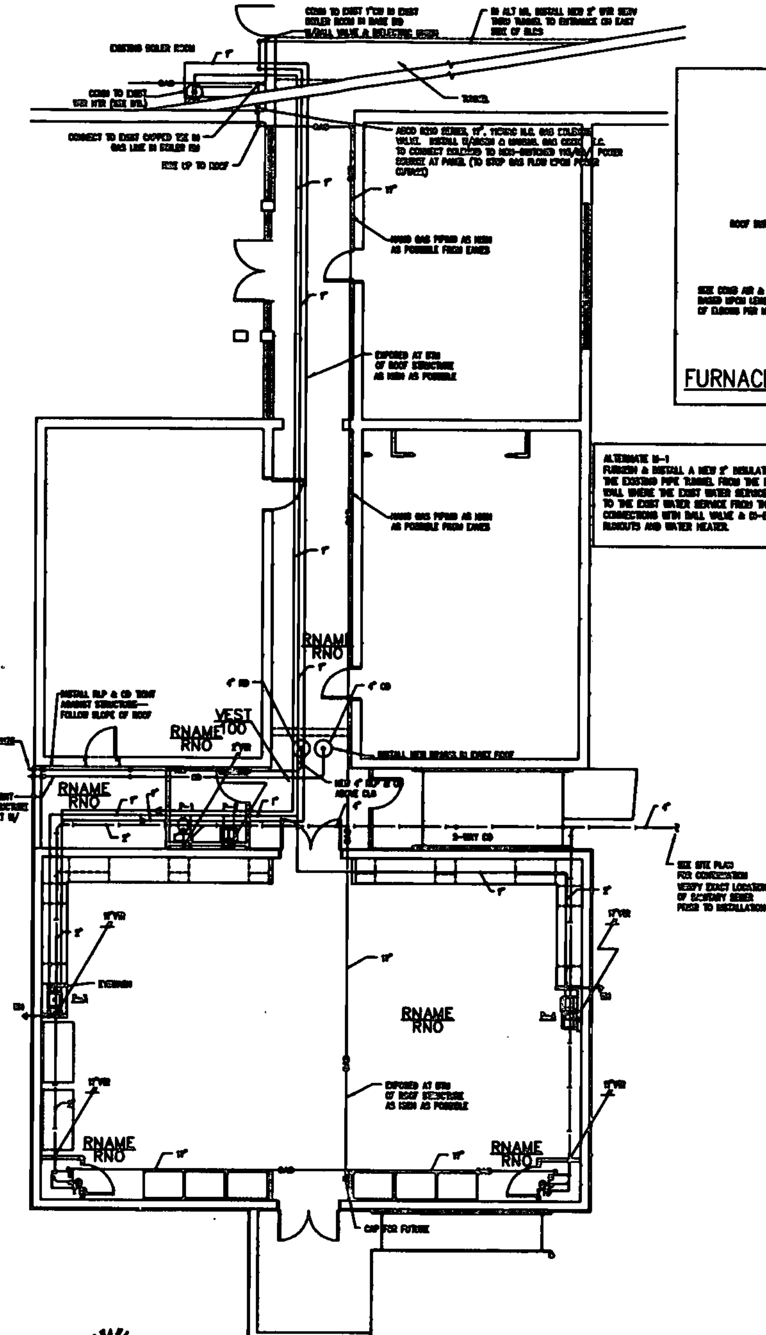
MARK	CFM	S.P.	H.P.	FAN R.P.M.	TIP SPEED	CURRENT	DRIVE	REMARKS
EF-1	100	1/4"	60W	1100	-	115/60/1ϕ	DIRECT	COOK LITTLE GEM

NOTE:

DIFFUSER & GRILLE SCHEDULE

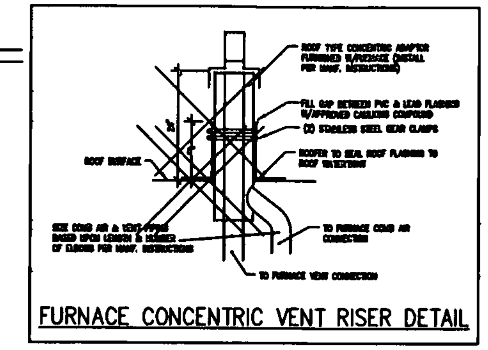
MARK	STYLE	DAMPER	REMARKS
A	SR	OBD	
B	RAG	—	
C	TDC	OBD	KRUEGER 1H SERIES

MARK / SIZE / CFM—#JAYS
CD—CEILING DIFF; CCD—CURVED BLADE DIFF; SR—SUPPLY REG; FD—FLOOR REG; TG—TRANSFER GR
RAG—RETURN AIR GR; ER—EXHAUST REG; EG—EXHAUST GR; FRAG—FLOOR RAG

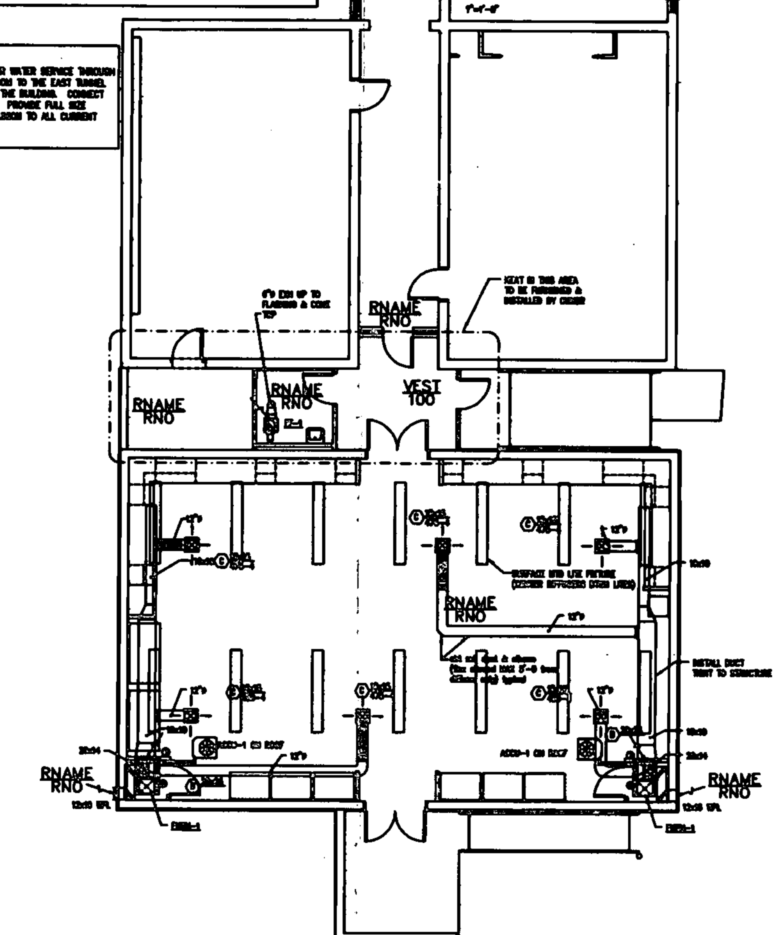


PLUMBING PLAN

1/4"=1'-0"



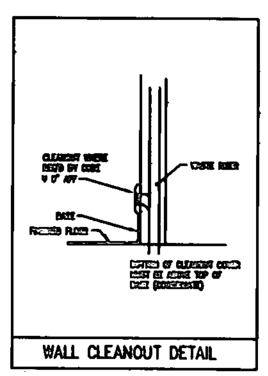
FURNACE CONCENTRIC VENT RISER DETAIL



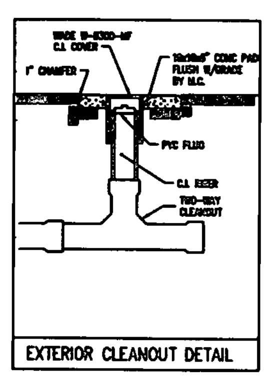
SECTION 'A'

HVAC PLAN

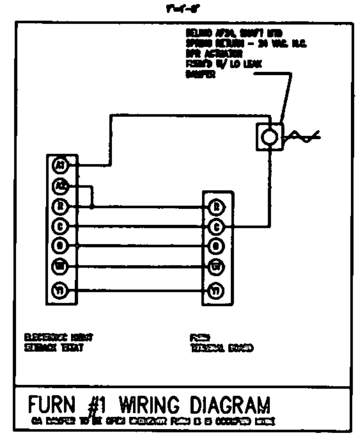
1/4"=1'-0"



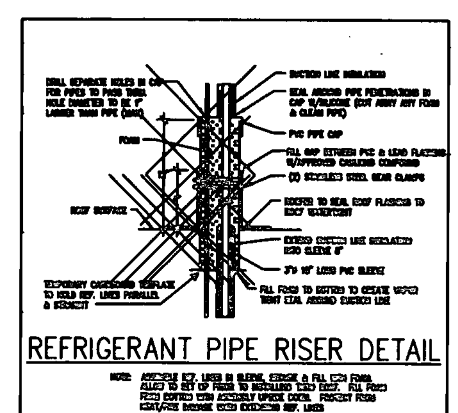
WALL CLEANOUT DETAIL



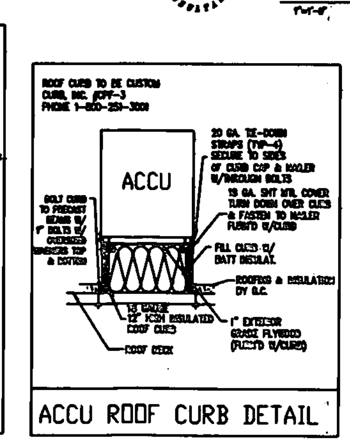
EXTERIOR CLEANOUT DETAIL



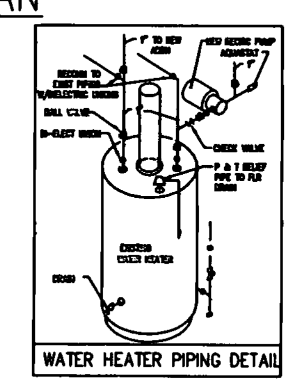
FURN #1 WIRING DIAGRAM



REFRIGERANT PIPE RISER DETAIL



ACCU ROOF CURB DETAIL



WATER HEATER PIPING DETAIL

LIMIT OF LIABILITY:

The designs included herein are based on extensive research of the causes and effects of windstorm damage to buildings.

Shelters designed and built to these designs should provide a high degree of occupant protection during tornadoes.

Any substitutions of either materials or design concepts may decrease the level of occupant protection and/or increase the possibility of personal injury during a severe wind event.

Because it is not possible to predict or test all conditions that may occur during severe windstorms, or control the quality of construction, among other things, the designer does not warrant the design.

The designer neither manufactures nor sells shelters built from this design. The designers have not made and do not make any representation, warranty, or covenant, express or implied, with respect to the design, condition, quality, durability, operation, fitness for use, or suitability of the shelter in any respect whatsoever.

Designers shall not be obligated or liable for actual, incidental, consequential, or other damages of or to users of shelters or any other person or entity arising out of or in connection with the use, condition, and/or performance of shelters built from this design or from the maintenance thereof.

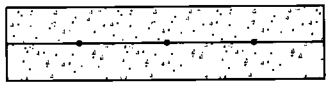
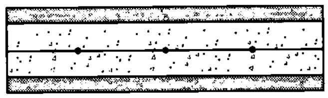
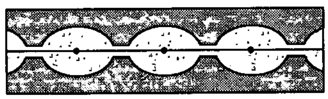
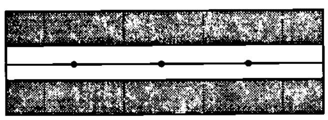
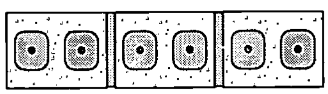
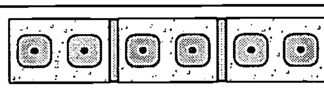
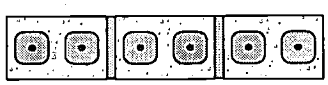
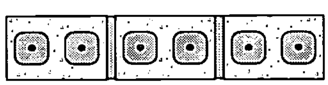
SHEET No.: P-1
DATE: 7 MARCH 2000
REVISED: | REV. NO.

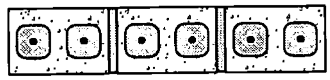
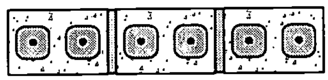
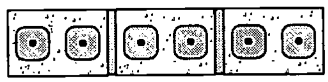
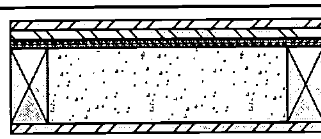
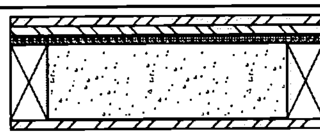
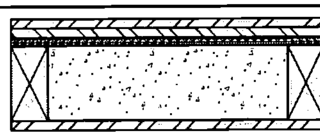
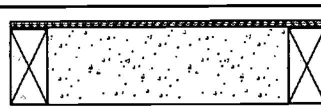
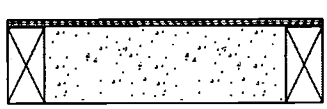
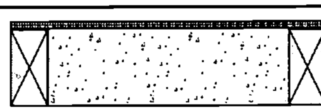
FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE WASHINGTON, DC

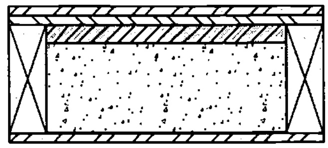
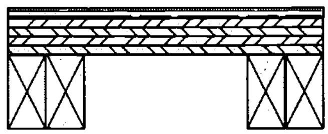
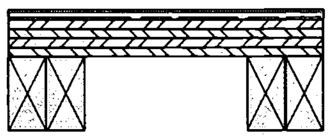
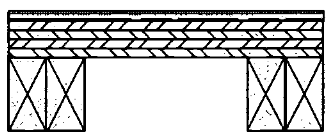
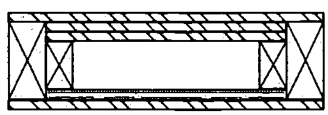
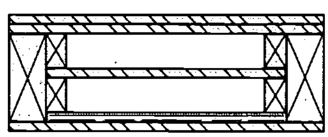
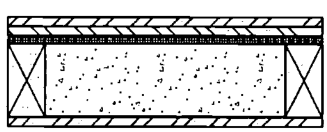
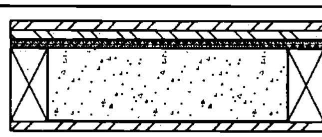
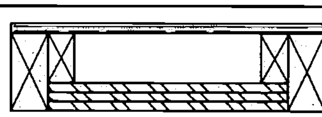
BEST COPY AVAILABLE

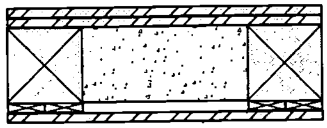
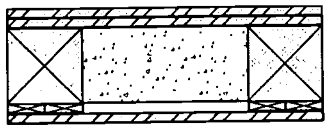
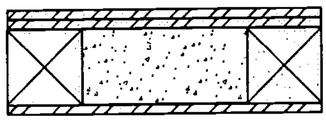
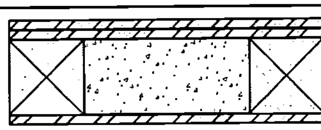
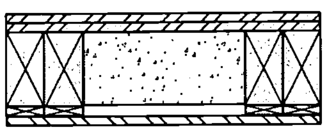
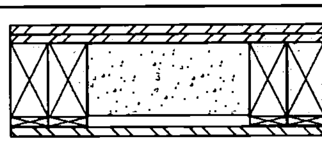
Appendix E
Wall Sections That Passed the Missile Impact Tests

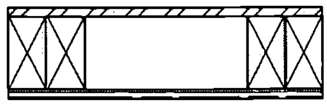
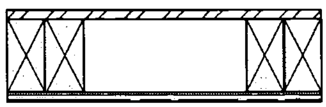
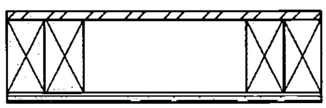
The following sheets document the performance of wall sections that passed the missile impact tests. The following information is provided for each wall section: description of the wall construction (e.g., stud wall with plywood and/or metal sheathing, stud wall with concrete infill, reinforced CMU wall, ICF wall), cross-section illustration, test missile speed, and description of damage.

Type of Wall Section (Target)	Description of Wall Section	Missile Speed (mph)	Description of Damage
Reinforced concrete wall, at least 6 in. thick, reinforced with #4 rebar every 12 in. (both vertically and horizontally)		100+	The target has been proven successful in previous tests.
Insulating concrete form (ICF) flat wall section at least 4" thick reinforced with #4 rebar every 12 in. (both vertically and horizontally)		100+	The target has been proven successful in previous tests.
Insulating concrete form (ICF) waffle grid wall section at least 6 in. thick reinforced with #5 rebar every 12 in. vertically and #4 rebar every 16 in. horizontally		100+	The target has been proven successful in previous tests.
Brick cavity wall reinforced with #4 rebar every 12 in. and concrete infill		100+	The target has been proven successful in previous tests.
8 in. CMU reinforced with concrete and #4 rebar in every cell		100+	The target was impacted over 30 times with the design missile. This was done for demonstration purposes. Only the first (verification) test was conducted as part of G&O contract.
6 in. CMU reinforced with concrete and #4 rebar in every cell		106.7	No damage was visible. 1/8 to 3/16 in. indentation on impact side.
6 in. CMU reinforced with concrete and #4 rebar in every cell		103.4	The missile impacted the target at a mortar joint. The target was cracked from the point of impact to the top of the target both in the front and in the back. The mortar spalled out of the joint on the back of the target.
6 in. CMU reinforced with concrete and #4 rebar in every cell		97.0	This target was tested previously. The second missile impacted the target in the same place as the first. The existing crack was extended into the base. A new crack appeared in the next joint 8 in. away and extended to the top of the target. The missile perforated the target and spalled the concrete fill out of the back of the target.

Type of Wall Section (Target)	Description of Wall Section	Missile Speed (mph)	Description of Damage
6 in. CMU reinforced with concrete and #4 rebar in every cell		No Time	No penetration of the target occurred. The target was cracked from the point of impact to the top of the target.
6 in. CMU reinforced with concrete and #4 rebar in every cell		111.3	The target was impacted at a vertical mortar joint. There was a 1/16 in. indentation on the impact face but no visible damage to either side of the target.
6 in. CMU reinforced with concrete and #4 rebar in every cell		106.9	The target was impacted at a vertical mortar joint. There was a 1/16 in. indentation on the impact face. The joint spalled slightly on the non-impact side. A small crack was detected at the impact point terminating at the top of the target.
2x4 stud wall with CD grade plywood, 14 ga. ½ in. expanded metal, and concrete infill		105.0	The missile impacted 4 in. to the left of a stud. No damage was visible on the back of the target.
2x4 stud wall with CD grade plywood, 14 ga. ½ in. expanded metal, and concrete infill		106.1	The missile impacted 1½ in. to the left of a stud. No damage was visible on the back of the target.
2x4 stud wall with CD grade plywood, 14 ga. ½ in. expanded metal, and concrete infill		105.4	The missile impacted 1 in. to the right of a stud. No damage was visible on the back of the target.
2x4 stud wall filled with concrete with no plywood and 14 ga. ½ in. expanded metal on the non-impact face		107.7	The missile made partial contact with the stud. The concrete was cracked around the impact area.
2x4 stud wall filled with concrete with no plywood and 14 ga. ½ in. expanded metal on the non-impact face		107.2	The missile made partial contact with the stud. The concrete was severely damaged, and a 4 in. deflection on the back of the target was observed.
2x4 stud wall filled with concrete with no plywood and 14 ga. ½ in. expanded metal on the non-impact face		107.1	The missile impacted the concrete. No damage was visible.
2x4 stud wall filled with concrete with no plywood and 14 ga. ½ in. expanded metal on the non-impact face		104.5	The missile hit the stud fully. There was 3 in. of deflection to the back of the target but no perforation.

Type of Wall Section (Target)	Description of Wall Section	Missile Speed (mph)	Description of Damage
4 in. concrete block in a 2x6 stud wall with 1½ in. of polystyrene between block and two layers of ¾ in. CD grade plywood.		111.3	The missile penetrated the target. There was no visible damage to the back side of the target.
Double 2x4 stud wall with 4 layers of ¾ in. CD grade plywood and 14 ga. steel on the back face		104-107	1 in. of deformation on the back face of the steel.
Double 2x4 stud wall with 4 layers of ¾ in. CD grade plywood and 14 ga. steel on the back face		106.6	The target was impacted next to a stud. Several heads of screws were popped off the back of the target. The steel had 1 in. of deformation.
Double 2x4 stud wall with 4 layers of ¾ in. CD grade plywood and 14 ga. steel on the back face		104.9	The target was impacted on the stud line. The stud was cut in two. No deformation was visible on the back side
4 layers of ¾ in. plywood with 14 ga. steel insert with spacers between the insert and the back face		109.4	The missile penetrated the target 1½-2 in. A crack in the plywood on the back face caused bending, but total separation did not occur.
14 ga. steel insert with spacers between all the inserts; the back face has two layers of ¾ in. CD grade plywood		108-110	The missile penetrated the target 1½-2 in. There was a crack in the plywood on the back face caused by bending, but total separation did not occur.
4 in. concrete block in a 2x4 stud wall with two layers of ¾ in. CD grade plywood and one layer of 14 ga. ½ in. expanded metal on the non-impact side and one layer of plywood on the impact side		106.7	¾ in. of penetration. There was no visible damage to the non-impact side.
4 in. concrete block in a 2x4 stud wall with two layers of ¾ in. CD grade plywood and one layer of 14 ga. ½ in. expanded metal on the non-impact side and one layer of plywood on the impact side		106.1	The missile impacted the stud and sheared it in two. There was no visible damage to the non-impact side.
2x4 stud wall with 3 layers of ¾ in. CD grade plywood inserts with 14 ga. metal on the non-impact side		105.7	The first insert of plywood failed in shear while the interior two failed in bending. The studs started to be torn in half, and there was 3 in. of deformation of the 14 ga. metal.

Type of Wall Section (Target)	Description of Wall Section	Missile Speed (mph)	Description of Damage
4x4 stud wall with 1x4's on the studs, containing 4 in. concrete block, gypsum board infill, and one layer of ¾ in. CD grade plywood on the impact face and two layers on the non-impact face		111.2	The missile impacted the stud, and ½ in. of deflection occurred on the non-impact side.
4x4 stud wall with 1x4's on the studs, containing 4 in. concrete block, gypsum board infill, and one layer of ¾ in. CD grade plywood on the impact face and two layers on the non-impact side		106.5	Missile penetrated the target, but did not perforate the target when it impacted at the interface between the block and the 4x4 stud.
4x4 stud wall, containing 4 in. concrete block, with one layer of 3/8 in. CD grade plywood on the impact face and two layers of ¾ in. CD grade plywood on the non-impact face		115.7	There was no missile penetration.
4x4 stud wall, containing 4 in. concrete block, with one layer of 3/8 in. CD grade plywood on the impact face and two layers of ¾ in. CD grade plywood on the non-impact face		109.0	The missile impacted the interface between the block and the 4x4 stud, perforating the target 3 ft.
Double 2x4 stud wall with furring, containing 4 in. block, with two layers of ¾ in. CD grade plywood on the non-impact face, one layer on the impact face, and a layer of 3/8 in. gyp. board on the imapct face.		103	The missile impacted ½ in. on the stud and ½ in. on the concrete block infill. There was ½ in. of deformation on the non-impact side.
Double 2x4 stud wall with furring, containing 4 in. block, with two layers of ¾ in. CD grade plywood on the non-impact face, one layer on the impact face, and a layer of 3/8 in. gyp. board on the imapct face.		100.7	The missile impacted next to the stud. There was ½ in. of deformation and cracking on the non-impact side.

Type of Wall Section (Target)	Description of Wall Section	Missile Speed (mph)	Description of Damage
Double 2x4 stud wall with one layer of 12 ga. steel on the impact side and one layer of ¾ in. CD grade plywood on the non-impact side.		**No time**	The missile impacted near the stud and was deflected.
Double 2x4 stud wall with one layer of 12 ga. steel on the impact side and one layer of ¾ in. CD grade plywood on the non-impact side.		**No Time**	The missile impacted the stud and was deflected, there was some damage to the non-impact face.
Double 2x4 stud wall with one layer of 12 ga. steel on the impact side and one layer of ¾ in. CD grade plywood on the non-impact side		**105.2**	The missile impacted next to the stud and was destroyed.
Double 2x4 stud wall with one layer of 12 ga. steel on the impact side and one layer of ¾ in. CD grade plywood on the non-impact side.		**103.6**	The missile impacted next to the stud and was destroyed.

Appendix F
Doors and Hardware That Passed the Missile Impact Tests

The tables on the following pages document the performance of some available doors and door hardware that passed the wind pressure and impact requirements of FEMA 320, *Taking Shelter From the Storm*. However, the testing program focused on a variety of doors and hardware systems rather than multiple tests of a single type of door system. The data presented are single-test results, which are intended to be used as indicators of expected performance.

A residential shelter in FEMA 320 is considered an enclosed structure ("enclosed" and "partially enclosed" buildings are defined by ASCE 7-98), that uses an internal pressure coefficient of $GC_{Pi} = \pm 0.18$ for components and cladding (C&C) design. Although impact requirements have not changed, the pressure coefficients for C&C of a community shelter are different from those used in FEMA 320. A community shelter is a larger building that will react differently to wind loads, requiring a design approach using internal pressure coefficients for partially enclosed buildings ($GC_{Pi} = \pm 0.55$). The use of higher internal pressure coefficients is described in Section 5.3.2, on page 5-10.

The change in pressure coefficients increased the design wind pressures for doors and windows in community shelters. Most of the door systems discussed in this manual and presented in this appendix have been successfully tested to wind pressure values associated with a 200-mph wind or Wind Zone III (Figure 2-2). However, many shelters will be located in Wind Zone IV (250 mph). The maximum wind pressures on a shelter occur at building corners. As of the time this manual was published, door/door hardware systems tested have not been tested to the maximum design pressures associated with Wind Zone IV at building corners. Therefore, any shelter door system in Wind Zone IV should be protected by an alcove or debris barrier until further testing can be performed or until other door and hardware systems are successfully tested for the design wind pressures.

This manual attempts to identify door/door hardware systems that are readily available from manufactures. All doors in this appendix have passed the missile impact criteria. Chapter 6 discussed wide single-door systems (greater than 36 inches wide, specifically 44-inch width) and double-door systems.

The wide single-door systems failed at 1.19 psi, which is less than the design wind pressures associated with 250-mph wind pressures. The double-door systems (composed of two 3-foot by 7-foot doors) were tested to the wind pressures of 1.37 psi without failure (the FEMA 320 design criteria). These doors were not tested to the 250-mph wind pressure levels.

It is important to note that the size of the door that is being tested will affect the design wind pressure to which a door should be designed. Specifically, the external pressure coefficient (GC_p) will vary with location along the wall (proximity to the building corner) and with the area of the door when calculating C&C loads using ASCE 7-98.

The testing of standard doors and door hardware will continue after the publication of this manual. The goal of this testing is to determine whether available doors and door hardware will be capable of resisting the highest of wind pressures associated with Wind Zone IV 250-mph winds. Updates on tested door systems will be posted on the Texas Tech University (TTU) web page at www.wind.ttu.edu. Questions regarding continued door testing may be directed to the TTU Outreach Center at 1-888-946-3287.

The information presented in this appendix includes the test date, a description of the door and door hardware tested, a brief description of the test results, and the test pressures or the missile impact speeds. The designer should note that these test results were derived from door systems that used door hardware systems that may not be accepted for egress under some occupancy classifications.

Results of Wind Pressure Tests on Doors With Individually Activated Latching Mechanisms

Date	Test Type	Door Description	Lock Description	Failure Pressure	Pressurization Results
3/31/98	Pressure	14 ga. steel door with 20 ga. metal ribs. The door was installed and tested as a swing-out door.	Sargent mortise lock with deadbolt function.	0.97 psi	Lock held to 0.97psi. The lock failed internally when the bar connecting the deadbolt bent, allowing the door to swing open.
3/6/98	Pressure	14 ga. steel door with polystyrene infill. The door was installed and tested as a swing-out door.		1.37 psi	The door failed at a pressure of 1.37 psi. The door failure was due to the failure of the lock set; also, the door did open due to the pressure.
3/26/98	Pressure	14 ga. door with a polystyrene infill. The door was mounted and tested as a swing-in door.	Yale mortise lock set with deadbolt function.	1.2 psi	The door failed at a pressure of 1.2 psi. The door failure was due to the failure of the lock set; also, the door did open due to the pressure.
3/31/98	Pressure	20 ga. door, a honeycomb infill, with a 14 ga. steel plate mounted on the non-impact side. The door was mounted and tested as a swing-in door.	Standard heavy-duty lock with three 1.2 in. slide bolts mounted opposite the hinges.	1.36 psi	The modified door held a pressure of 1.36 psi for 5 seconds.
4/1/98	Pressure	20 ga. door, a honeycomb infill, with a 14 ga. steel plate mounted on the non-impact side. The door was mounted and tested as a swing-in door.	Standard heavy-duty lock with three 1.2 in. slide bolts mounted opposite the hinges.	1.46 psi	The modified door held a pressure of 1.46 psi for 5 seconds.
5/98	Pressure	Six-panel metal-covered wood-frame door with a sheet of 14 ga. steel attached.	Standard off-the-shelf doorknob with three deadbolt locks placed opposite the hinges.	1.21 psi	The modified door failed at the location of the deadbolts at 1.21 psi. The hardware appeared to cause the door to fail.
5/98	Pressure	Solid-core wood door with a sheet of 14 ga. steel attached.	Standard off-the-shelf doorknob with three deadbolt locks placed opposite the hinges.	1.13 psi	The modified door failed at the location of the deadbolts at 1.13 psi. The hardware appeared to cause the door to fail.
5/98	Pressure	Six-panel solid-wood door with a sheet of 14 ga. steel attached.	Standard off-the-shelf doorknob with three deadbolt locks placed opposite the hinges.	1.12 psi	The modified door failed at the location of the deadbolts at 1.12 psi. The hardware appeared to cause the door to fail.

Results of Missile Impact Tests on Doors With Individually Activated Latching Mechanisms

Date	Test Type	Door Description	Lock Description	Missile Threshold (mph)	Impact Results	Impact Speed (mph)
	Missile	14 ga. steel door with 20 ga. metal ribs. The door was installed and tested as a swing-out door.	Sargent mortise lock with deadbolt function.	> 100	The door withstood several impacts at the midpoint of the door next to the hardware and at the upper and lower corners next to the hinges and on the lock side, respectively.	82.35 81.99 104.83 106.57
3/26/98	Missile	14 ga. door with a polystyrene infill. The door was mounted and tested as a swing-in door.	Yale mortise lock with deadbolt function.	81	Door failed the impact test due to hardware failure. When modified with three slide bolt locks, mounted opposite the hinges, the door is successful.	81.3
3/31/98	Missile	20 ga. door, a honeycomb infill, with a 14 ga. steel plate mounted on the non-impact side. The door was mounted and tested as a swing-in door.	Standard heavy duty lock with three 1/2 in. slide bolts mounted opposite the hinges.	104	There was a local failure of the hardware, but the redudndanies in the hardware held the door in place. The missile penetrated the impact skin, but did not perforate the non-impact side or the 14 ga. steel plate. There was permanent deformation.	103.88
4/1/98	Missile	20 ga. door, a honeycomb infill, with a 14 ga. steel plate mounted on the non-impact side. The door was mounted and tested as a swing-in door.		104	The missile did not penetrate the door, but it caused permanent deformation in the internal door frame. (The door buckled around the standard lock set.)	104.09

Results of Wind Pressure and Missile Impact Tests on Double-Door Set With Panic Bar Hardware and Single-Action Lever Hardware

Date	Test Type	Door Description	Hardware Description	Test Results
5/00	Pressure and Missile	3 ft. x 7 ft steel 14 ga. door with 14 ga. steel channels as hinge and lock rails and 16 ga. channels at top and bottom (see page 6-14, Section 6.4.1.1). Polystyrene infill or honeycomb core. 14 ga. steel frame with 14 ga. center steel mullion (see page 6-15, Section 6.4.1.3).	Externally mounted three-point latching mechanism with panic bar release, 5/8 in. headbolt and footbolt with 1 in. throw, and mortised center deadbolt.	Pressure reached 1.37 psi without failure. Missile impact at 100 mph did not perforate.
5/00	Pressure and Missile	3 ft. x 7 ft steel 14 ga. door with 14 ga. steel channels as hinge and lock rails and 16 ga. channels at top and bottom (see page 6-14, Section 6.4.1.1). Polystyrene infill or honeycomb core. 14 ga. steel frame with 14 ga. center steel mullion (see page 6-15, Section 6.4.1.3)	Externally mounted three-point latching mechanism with single-action lever release, 1 in. solid mortised center deadbolt with 1 in. throw, and two 1 in. x 3/8 in. solid hookbolts, one below and one above the deadbolt.	Pressure reached 1.37 psi without failure of door, although top hookbolt failed. Missile Imapct at 100 mph pushed door through frame, causing center mullion to rotate. Testing inconclusive; further testing required.

273

BEST COPY AVAILABLE

272

Appendix G
Design Guidance on Missile Impact Protection Levels for Wood Sheathing

Reinforced concrete and reinforced masonry have been the most common wall and roof materials used with success in non-residential shelters. The use of wood panels for exterior wall sheathing in non-residential shelter applications had been limited. This appendix provides limited information on wood panel testing that has been performed for both hurricane and tornado shelter applications.

Data from the missile impact tests on walls with plywood and oriented strand board (OSB) sheathing conducted at Texas Tech University (Carter 1998) and at Clemson University (Clemson 2000) have been combined to determine the variation of missile perforation resistance with thickness of the sheathing. In order to put all the data on a consistent basis, missile weights and lowest impact velocities for perforation of the sheathing have been extracted from previous test results. The weight and impact velocity information were used to calculate the impact momentum {weight (lb) x velocity (ft/sec) / acceleration of gravity (32.2 ft/sec2) = momentum (lb/sec)} and the impact energy {weight (lb.) x velocity squared (ft/sec) 2 / acceleration of gravity (32.2 ft/sec2) = energy (ft/lb)}. The resulting impact momentum and impact energy for perforation of the sheathing are plotted as a function of sheathing thickness (in 1/32 inch) in Figures G-1 and G-2.

The momentum required for a wood 2x4 missile to cause perforation varies essentially linearly with thickness of the sheathing material for both plywood and OSB. This suggests, at least for this type of missile and common sheathing materials, that a desired target penetration resistance (ability to resist a certain impact momentum) can be achieved by simply adding up the contributions of the various layers of sheathing. For example, in Figure G-1, sheathing with a 30/32-inch thickness represent two layers of 15/32-inch material.

Figure G-1
Variation of impact momentum required for missile penetration vs. wall sheathing thickness.

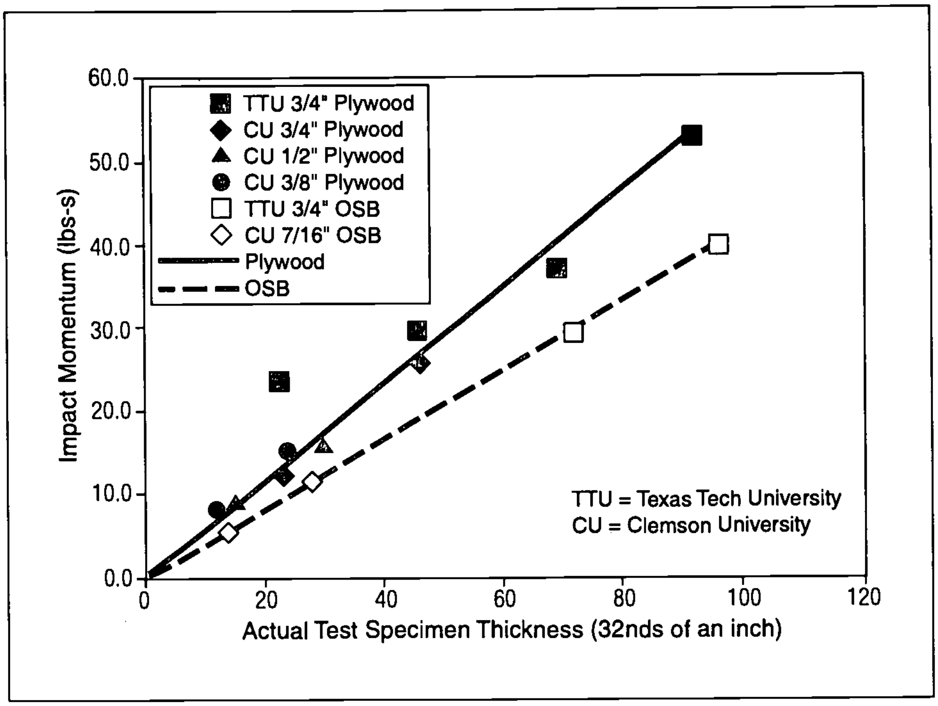


Figure G-2
Variation of impact energy required for missile penetration vs. wall sheathing thickness.

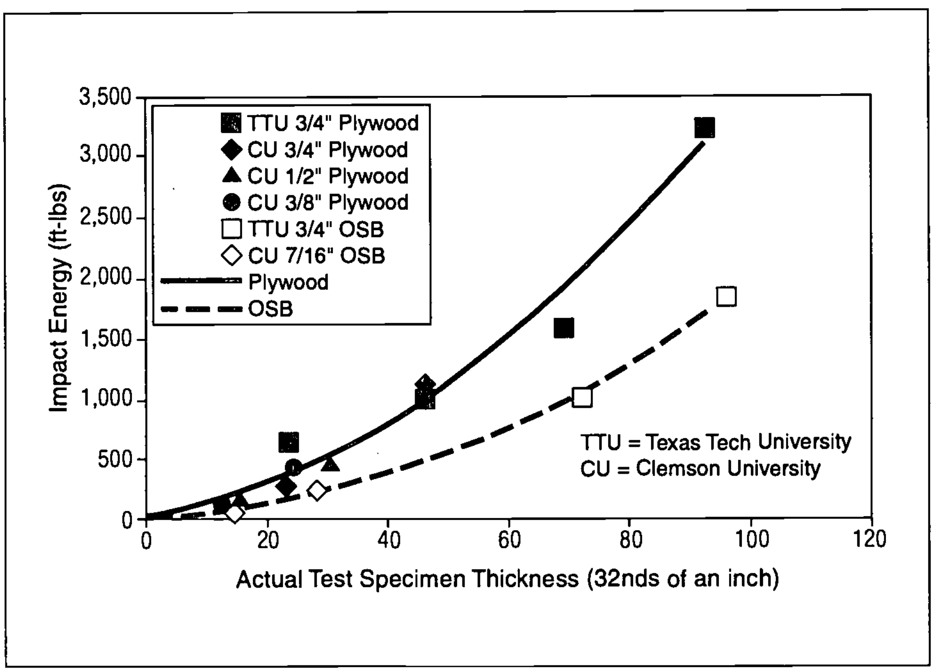


Figure G-3 provides information on the relative resistance of various common sheathing materials, in terms of impact momentum absorption, for a compact impact area such as that associated with a wood 2x4 missile impacting perpendicular to the sheathing material. Summing the momentum resistance of the various layers of common sheathing materials is permissible when developing initial design criteria for walls that provide adequate protection. However, this process may not work for other types of missiles or for wall materials that absorb impact energy by undergoing large deformations (i.e., corrugated metal panels).

For the design missile of this manual (a 15-lb wood 2x4 missile with a horizontal impact speed of 100 mph), the corresponding momentum is approximately 68 lb/sec. For vertical impacts, the impact velocity is reduced to 67 mph and the corresponding momentum is approximately 46 lb/sec.

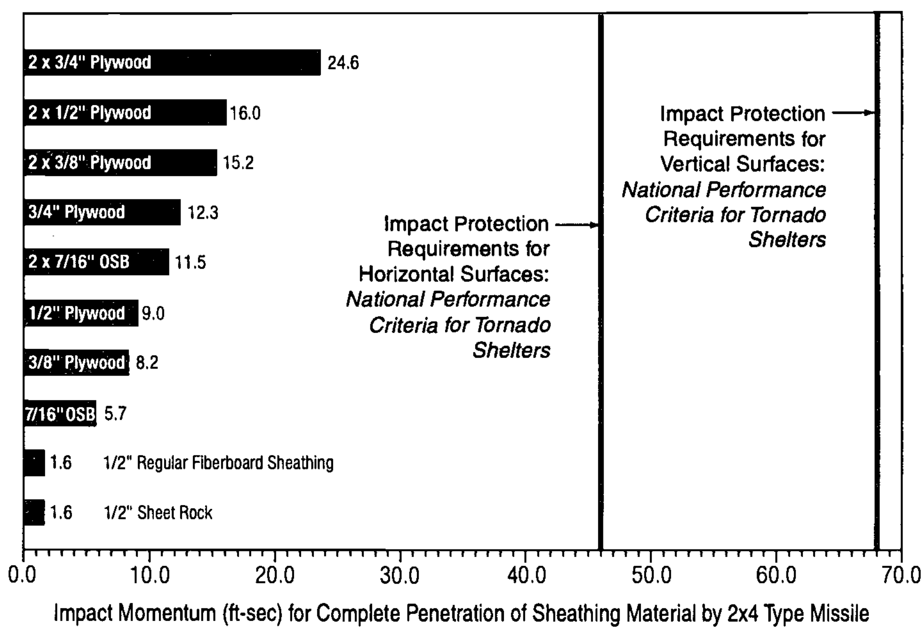


Figure G-3
Impact momentum required for a 2x4 wood missile to penetrate various common sheathing materials (impact perpendicular to sheathing surface). Note: All wood products provide less than half the required impact momentum resistance needed to meet the horizontal surface impact resistance required by the *National Performance Criteria for Tornado Shelters.*

NOTICE

REPRODUCTION BASIS

☐ This document is covered by a signed "Reproduction Release (Blanket) form (on file within the ERIC system), encompassing all or classes of documents from its source organization and, therefore, does not require a "Specific Document" Release form.

☒ This document is Federally-funded, or carries its own permission to reproduce, or is otherwise in the public domain and, therefore, may be reproduced by ERIC without a signed Reproduction Release form (either "Specific Document" or "Blanket").